United States
Environmental Protection
Agency

EPA-600/2-86-079
September 1986

EPA

# Research and Development

①

AD-A173 021

# DESTRUCTION OF CHLORINATED HYDROCARBONS BY CATALYTIC OXIDATION

## Prepared for

Office of Air Quality Planning and Standards

## Prepared by

Air and Energy Engineering Research
Laboratory
Research Triangle Park NC 27711

DTIC FILE COPY

DTIC
ELECTE
OCT 1 0 1986

This document has been approved
for public release and sale; its
distribution is unlimited.

86 10 6 100

## RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

## EPA REVIEW NOTICE

This report has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policy of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

①

EPA/600/2-86-079
September 1986

# DESTRUCTION OF CHLORINATED HYDROCARBONS BY CATALYTIC OXIDATION

Prepared by:

M. A. Palazzolo, C. L. Jamgochian
J. I. Steinmetz and D. L. Lewis
Radian Corporation
Progress Center
3200 E. Chapel Hill Rd./Nelson Hwy.
Research Triangle Park, North Carolina 27709

EPA Contract
68-02-3994, Tasks 20 and 34
USAF Interagency Agreement
RW57931254

EPA Project Officer: Bruce A. Tichenor
Air and Energy Engineering Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, North Carolina 27711

USAF Project Officer:
Captain Richard A. Ashworth
U.S. Air Force Engineering and Services Center
Tyndall Air Force Base, Florida 32403

Prepared for:

U. S. Environmental Protection Agency
Office of Research and Development
Washington, D.C. 20460

In cooperation with:
U. S. Air Force
Engineering and Services Center
Tyndall Air Force Base, Florida 32403

DTIC
S ELECTE D
OCT 1 0 1986
A

This document has been approved
for public release and sale; its
distribution is unlimited.

# ABSTRACT

This report provides the results of a study conducted to determine the effectiveness of catalytic oxidation for destroying vapor phase chlorinated hydrocarbons. The study was conducted on two pilot scale catalytic incinerator systems leased from vendors. One system employed a metal oxide catalyst in a fluidized bed configuration. The other system used a fixed bed proprietary catalyst, supplemented with UV light and ozone injection. Both systems were tested under a variety of temperatures and space velocities. The test vapor streams consisted of low concentrations (3 to 200 ppmv) of mixtures of organic compounds, and included three streams which represented the emissions from air strippers used to treat contaminated groundwater at U.S. Air Force bases. The study results showed that the fluidizied bed catalytic incinerator system was capable of achieving total organic destruction efficiencies of greater than 98%. The UV/ozone catalytic system failed to achieve high destruction efficiencies; with ozone injection, total desctruction was 75%; without ozone, the maximum destruction efficiency was 64%.

destruction

QUALITY INSPECTED 4

Accession For
NTIS GRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification

By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

TABLE OF CONTENTS

| Section | Title | Page |
|---|---|---|
| | List of Figures | v |
| | List of Tables | vii |
| | Acknowledgements | ix |
| 1.0 | Introduction | 1 |
| 2.0 | Summary | 3 |
| 3.0 | Test System Descriptions | 11 |
| | 3.1 Fluidized-bed Catalytic Incinerator System Description | 11 |
| | 3.2 UV-Catalytic System | 13 |
| | 3.3 Test Mixture Vapor Generation System | 15 |
| 4.0 | Experimental Design | 21 |
| | 4.1 Test Parameters | 21 |
| | 4.2 Test Matrices | 26 |
| 5.0 | Sampling Systems and Analytic Procedures | 29 |
| | 5.1 Sampling Procedures | 29 |
| | 5.1.1 Fluidized-bed Catalytic Incinerator | 31 |
| | 5.1.2 UV-Catalytic Oxidizer | 34 |
| | 5.2 Analytical Methods | 36 |
| | 5.2.1 EPA Method 18 | 36 |
| | 5.2.2 Analytical Method for GC/FID Analysis of Tenax | 38 |
| | 5.2.3 GC/MS Analytical Procedures | 41 |
| | 5.2.4 Carbon Monoxide Analysis | 41 |
| 6.0 | Statistical Methods | 45 |
| 7.0 | Fluidized-Bed Incinerator Results | 47 |
| | 7.1 Effects Of Inlet Temperature and Space Velocity | 48 |
| | 7.1.1 Effects on Mixture Destruction | 48 |
| | 7.1.2 Effects on Component Destruction | 56 |
| | 7.2 Mixture Effects | 59 |
| | 7.3 Relative Compound Destructability | 63 |
| | 7.4 Effect of Inlet Concentration | 66 |
| | 7.5 Products of Incomplete Oxidation | 66 |
| | 7.5.1 GC/MS Results | 66 |
| | 7.5.2 Carbon Monoxide Emissions | 69 |
| | 7.6 Potential HCL Emissions | 69 |
| | 7.7 Comparison of Method 18 and Tenax-GC Data | 71 |
| 8.0 | UV-Catalytic Oxidizer Results | 73 |
| | 8.1 Oxidation Without Ozone | 73 |
| | 8.2 Oxidation With Ozone | 73 |

TABLE OF CONTENTS
(cont'd.)

| Section | Title | Page |
|---|---|---|
| 9.0 | Conclusions and Recommendations. . . . . . . . . . . . . . . . . . . | 77 |
| 9.1 | Conclusions . . . . . . . . . . . . . . . . . . . . . . . | 77 |
| 9.2 | Recommendations . . . . . . . . . . . . . . . . . . . . . | 78 |
| 10.0 | References . . . . . . . . . . . . . . . . . . . . . . . . . | 80 |
| Appendix A | QA/QC Results . . . . . . . . . . . . . . . . . . . . . . . | A-1 |
| Appendix B | Unit Conversions. . . . . . . . . . . . . . . . . . . . . . | B-1 |
| Appendix C | Method 18 and Tenax-GC Data for Fluidized Bed Incinerator . | C-1 |

## LIST OF FIGURES

| Figure | Title | Page |
|---|---|---|
| 2-1 | System Destruction Efficiencies as a Function of Catalyst Inlet Temperature for All Mixtures at a Space Velocity of 10,500 $hr^{-1}$ . . . . . . . . . . . . . . . . . . . . . . . . | 7 |
| 3-1 | Fluidized-bed Catalytic Incinerator System. . . . . . . . . . . . | 12 |
| 3-2 | Schematic Diagram of Pilot-Scale UV-Catalytic Test System . . . . | 14 |
| 3-3 | Test Mixture Vapor Generation System For Fluidized-bed Catalytic Incinerator . . . . . . . . . . . . . . . . . . . . . | 16 |
| 3-4 | High Volume Liquid Feed System. . . . . . . . . . . . . . . . . . | 18 |
| 3-5 | Test Mixture Vapor Generation System for UV-Catalytic Oxidizer. . | 19 |
| 5-1 | Sampling Diagram for Fluidized-bed Catalytic Incinerator. . . . . | 32 |
| 5-2 | Tenax-GC Resin Sampling Train . . . . . . . . . . . . . . . . . . | 33 |
| 5-3 | Sampling Diagram for UV-Catalytic Oxidizer. . . . . . . . . . . . | 35 |
| 5-4 | Flow Diagram for Tenax-GC Resin Sample Analysis . . . . . . . . . | 39 |
| 7-1 | System Destruction Efficiencies as a Function of Catalyst Inlet Temperature for All Mixtures at a Space Velocity of 10,500 $hr^{-1}$ . . . . . . . . . . . . . . . . . . . . . . . . | 52 |
| 7-2 | System Destruction Efficiencies as a Function of Catalyst Inlet Temperature for all Mixtures at a Space Velocity of 7,000 $hr^{-1}$ . . . . . . . . . . . . . . . . . . . . . . . . | 52 |
| 7-3 | Catalyst Destruction Efficiencies as a Function of Catalyst Inlet Temperature for all Four Mixtures at a Space Velocity of 10,500 $hr^{-1}$ . . . . . . . . . . . . . . . . . . . . . . . . | 53 |
| 7-4 | Heater Destruction Efficiencies as a Function of Temperature for all Mixtures at Two Space Velocities. . . . . . . . . . . | 54 |
| 7-5 | Component System Destruction Efficiency as a Function of Catalyst Inlet Temperature for Mixture 1 at a Space Velocity of 10,500 $hr^{-1}$ . . . . . . . . . . . . . . . . . . . . . . . . | 55 |
| 7-6 | Component System Destruction Efficiency as a Function of Catalyst Inlet Temperature for Mixture 3 at a Space Velocity of 10,500 $hr^{-1}$ . . . . . . . . . . . . . . . . . . . . . . . . | 57 |

## LIST OF FIGURES
## (cont'd.)

| Figure | Title | Page |
|---|---|---|
| 7-7 | Component System Destruction Efficiency as a Function of Catalyst Inlet Temperature for Mixture 4 at a Space Velocity of 10,500 $hr^{-1}$ | 58 |
| 7-8 | Component System Destruction Efficiency as a Function of Catalyst Inlet Temperature for Mixture 2 at a Space Velocity of 10,500 $hr^{-1}$ | 61 |
| 7-9 | Component System Destruction Efficiency as a Function of Catalyst Inlet Temperature for Mixture 2 at a Space Velocity of 7,000 $hr^{-1}$ | 62 |
| 7-10 | CO Concentration at the Outlet Stack as a Function of Preheater Temperature for All Test Runs | 70 |

## LIST OF TABLES

| Table | Title | Page |
|---|---|---|
| 2-1 | Mixture Compositions and Target Concentrations for Catalytic Oxidation Tests | 5 |
| 2-2 | Summary of Operating Conditions Tested | 6 |
| 4-1 | Test Parameters and Conditions for Fluidized Bed Catalytic Incinerator | 23 |
| 4-2 | Mixture Compositions and Target Concentrations For Catalytic Oxidation Tests | 24 |
| 4-3 | Test Parameters and Conditions for UV-Catalytic Oxidizer | 25 |
| 4-4 | Test Matrix for UV-Catalytic Oxidizer (Series A) | 27 |
| 4-5 | Test Matrix for the Fluidized-Bed Catalytic Incinerator (Series B) | 28 |
| 5-1 | Summary of Sampling and Analytical Methods | 30 |
| 5-2 | GC Conditions for Method 18 Analysis | 37 |
| 5-3 | GC Conditions for Varian 3400 | 40 |
| 5-4 | Results of Breakthrough Study | 42 |
| 7-1 | Mixture Compositions for Catalytic Oxidation Tests | 49 |
| 7-2 | Summary of System Parameters and System, Catalyst and Heater Destruction Efficiencies for the Fluidized-Bed Catalytic Incinerator Test System | 50 |
| 7-3 | Comparison of Trichloroethylene System and Catalyst Destruction Efficiencies in Different Mixtures | 64 |
| 7-4 | Relative Destructability of Test Compounds | 65 |
| 7-5 | Effect of Inlet Concentration on Mixture 4 Destruction Efficiency | 67 |
| 7-6 | Summary of GC/MS Analysis for Products of Incomplete Oxidation | 68 |
| 7-7 | Theoretical HCl Concentrations in Outlet Gas For Mixtures 1, 2, and 3 | 72 |

## LIST OF TABLES
(cont'd.)

Table | Title | Page

8-1 Summary of Mixture 1 Results Without Ozone for the UV-Catalytic Oxidizer. . . . . . . . . . . . . . . . . . . . . . . . . . . . 74

8-2 Summary of Mixture 1 Results With Ozone for the UV-Catalytic Oxidizer. . . . . . . . . . . . . . . . . . . . . . . . . . . . 75

# ACKNOWLEDGEMENTS

The research described in this report was performed, in part, under an interagency agreement, between the U. S. Environmental Protection Agency (RW 57931254) and the Engineering Services Laboratory of the U.S. Air Force Engineering and Services Center, entitled "Catalytic Destruction of Volatile Organic Compounds (VOC's)."

# 1.0 INTRODUCTION

This report describes a test program conducted by Radian Corporation for the EPA and the Air Force to investigate, on an experimental scale, the effectiveness of catalytic oxidation as a means of destroying specific volatile organic compounds (VOC) and hazardous/toxic air pollutants (HAP). Two pilot-scale catalytic oxidation units and a test mixture vapor generation system were used to conduct this testing. All measurements were conducted in accordance with a Quality Assurance Project Plan approved by EPA.

Objectives of the study were broad and two-fold. One objective was to generate additional publicly available data on the performance of commercial catalytic oxidizers, with particular emphasis on chlorinated hydrocarbons. An earlier study conducted under EPA funding investigated effects of operating conditions on the destruction of different mixtures containing compounds in different chemical classes (e.g. alkanes, alcohols, aldehydes, ketones, etc.)[1] The earlier program showed poor destruction efficiencies for chlorinated hydrocarbons with the particular type of catalyst used. Thus, the efforts of this program were specifically directed toward providing data on the catalytic oxidation of chlorinated hydrocarbons.

The second objective of this test program was to investigate the performance of commercially available catalytic oxidation systems that may be suitable for the treatment of gas streams from air strippers used in groundwater cleanup. Three of four hydrocarbon mixtures selected for testing were representative of actual off-gases from such air strippers.

This report is divided into nine sections. A summary of the experimental approach and the test results is presented in Section 2. The catalytic oxidation units and the solvent vapor generation system are described in Section 3 and details of the experimental design are discussed in Section 4. Sampling and analytical methods are discussed in Section 5. Statistical techniques used in the data analysis are presented in Section 6 and results of testing and analysis are discussed in Sections 7 and 8. The final section lists conclusions and recommendations based on the study. Quality Assurance and Quality Control results are presented in Appendix A.

# 2.0 SUMMARY

Parametric testing of two different skid-mounted catalytic oxidation systems was performed to assess the effects of operating and design parameters on the destruction efficiency of low concentration VOC/HAP mixtures in air. The oxidation systems tested included a 500 scfm* fluidized-bed catalytic incinerator leased from ARI International and a 20 scfm ultraviolet (UV)-catalytic oxidizer leased from Ultrox International. A test compound vapor generation system, which included a pump, a glass mixing chamber, and motor-driven syringes, was used to produce spiked air streams with the desired concentration of organic vapors. Total mixture, as well as compound specific, destruction efficiencies were determined.

## Experimental Design

Prior to initiating the test program, major vendors of catalytic oxidation systems were contacted to: (1) investigate the availability of catalysts and catalytic systems suitable for destroying chlorinated hydrocarbons and (2) identify those vendors with existing laboratory- or pilot-scale units that could be tested under this program. This effort identified only the two systems tested.

Major operating parameters that were varied during the fluidized-bed incinerator testing included VOC/HAP mixture, catalyst inlet temperature, space velocity, and inlet concentration. Testing was generally conducted to characterize destruction across the gas-fired preheater and the catalyst bed as a "system". However, heater and catalyst destruction efficiencies were also determined separately at most test conditions.

Operating parameters that were varied during the UV-catalytic oxidizer testing included space velocity, inlet concentration, UV intensity, humidity and ozone addition.

---

*To conform with general engineering practice, English Engineering units rather than metric units are normally used in this report. Appendix B provides conversion factors from English Engineering to International System (SI) units.

Components and target concentrations for the test mixtures are presented in Table 2-1. All four mixtures shown in Table 2-1 were tested with the fluidized-bed system, but only one mixture was tested with the UV-catalytic oxidizer. The ranges of operating conditions tested for the two catalytic systems are summarized in Table 2-2. As shown in Table 2-2, the fluidized bed system was tested at two space velocities for catalyst inlet temperatures ranging from 650 to 950°F. Two inlet concentrations for Mixture 4 were also tested. The UV-catalytic oxidizer was tested at three space velocities, two humidities and with/without ozone addition. Two inlet concentrations for Mixture 1 were also tested.

## Fluidized-Bed Incinerator Results

Results for the fluidized-bed incinerator showed average system destruction efficiencies for total VOC's in the 97 to 99 percent range for all four test mixtures. Catalyst inlet temperature showed a strong effect on destruction efficiency, while mixture composition, air-to-gas (fuel) ratio, space velocity, and inlet concentration all showed marginal or statistically insignificant effects.

The effect of catalyst inlet temperature on mixture system destruction efficiencies is shown in Figure 2-1 for a space velocity of 10,500 $hr^{-1}$. Comparison of destruction efficiencies for the different mixtures shows that the highest efficiencies were observed for Mixture 2 and the lowest efficiencies were observed for Mixture 4. The low destruction efficiency of Mixture 4 is attributed to the presence of tetrachloroethylene in this mixture. Tetrachloroethylene showed the lowest destruction efficiency of the 10 compounds tested.

The effect of catalyst inlet temperature on component destruction efficiency was similar for most of the test compounds with the exception of trichloroethylene and benzene in Mixture 2. These compounds, and in particular benzene, showed a very sharp increase in destruction between temperatures of 650° and 800°F. One possible explanation for the observed effect is the low concentration of benzene and trichloroethylene in Mixture 2 relative to the other three compounds.

## TABLE 2-1. MIXTURE COMPOSITIONS AND TARGET CONCENTRATIONS FOR CATALYTIC OXIDATION TESTS

| Mixture Designation | Concentration Level | Mixture Compounds | Target Inlet Concentration (ppmv)[a] |
|---|---|---|---|
| Mixture 1 | Baseline | Trichloroethylene | 6.3 |
| | | 1,2 dichloroethylene | 8.5 |
| | | | 14.8 |
| Mixture 1 | Low | Trichloroethylene | 1.9 |
| | | 1,2 dichloroethylene | 1.0 |
| | | | 2.9 |
| Mixture 2 | Baseline | Trichloroethylene | 2.7 |
| | | Benzene | 1.5 |
| | | Ethylbenzene | 5.6 |
| | | Pentane | 11.5 |
| | | Cyclohexane | 14.1 |
| | | | 35.4 |
| Mixture 3 | Baseline | Vinyl Chloride | 7.5 |
| | | Trichloroethylene | 1.8 |
| | | | 9.3 |
| Mixture 4 | Baseline | 1,2 dichloroethane | 10 |
| | | Trichloroethylene | 10 |
| | | 1,1,2-trichloroethane | 10 |
| | | Tetrachloroethylene | 10 |
| | | | 40 |
| Mixture 4 | High | 1,2 dichloroethane | 50 |
| | | Trichloroethylene | 50 |
| | | 1,1,2-trichloroethane | 50 |
| | | Tetrachloroethylene | 50 |
| | | | 200 |

[a] ppmv = parts per million by volume as compound.

TABLE 2-2. SUMMARY OF OPERATING CONDITIONS TESTED

| Catalytic System | Test Parameter | Conditions Or Values Tested |
|---|---|---|
| Fluidized-Bed Incinerator | VOC/HAP Mixture | Mixtures 1, 2, 3, & 4 |
| | Space Velocity | 7,000 and 10,500 $hr^{-1}$ |
| | Operating Temperature (Catalyst Inlet) | 650° to 950°F |
| | Inlet Concentration | Baseline and High[a] |
| UV-Oxidizer | VOC/HAP Mixture | Mixture 1 |
| | Space Velocity | 200 to 3000 $hr^{-1}$ (1 to 15 scfm) |
| | Inlet Concentration | Baseline and Low[a] |
| | Humidity | Ambient<br>150% Ambient |
| | Ozone | Without Ozone<br>With Ozone |
| | UV Intensity | UV Lamps On<br>UV Lamps Off |

[a] Mixtures and concentrations are summarized in Table 2-1.

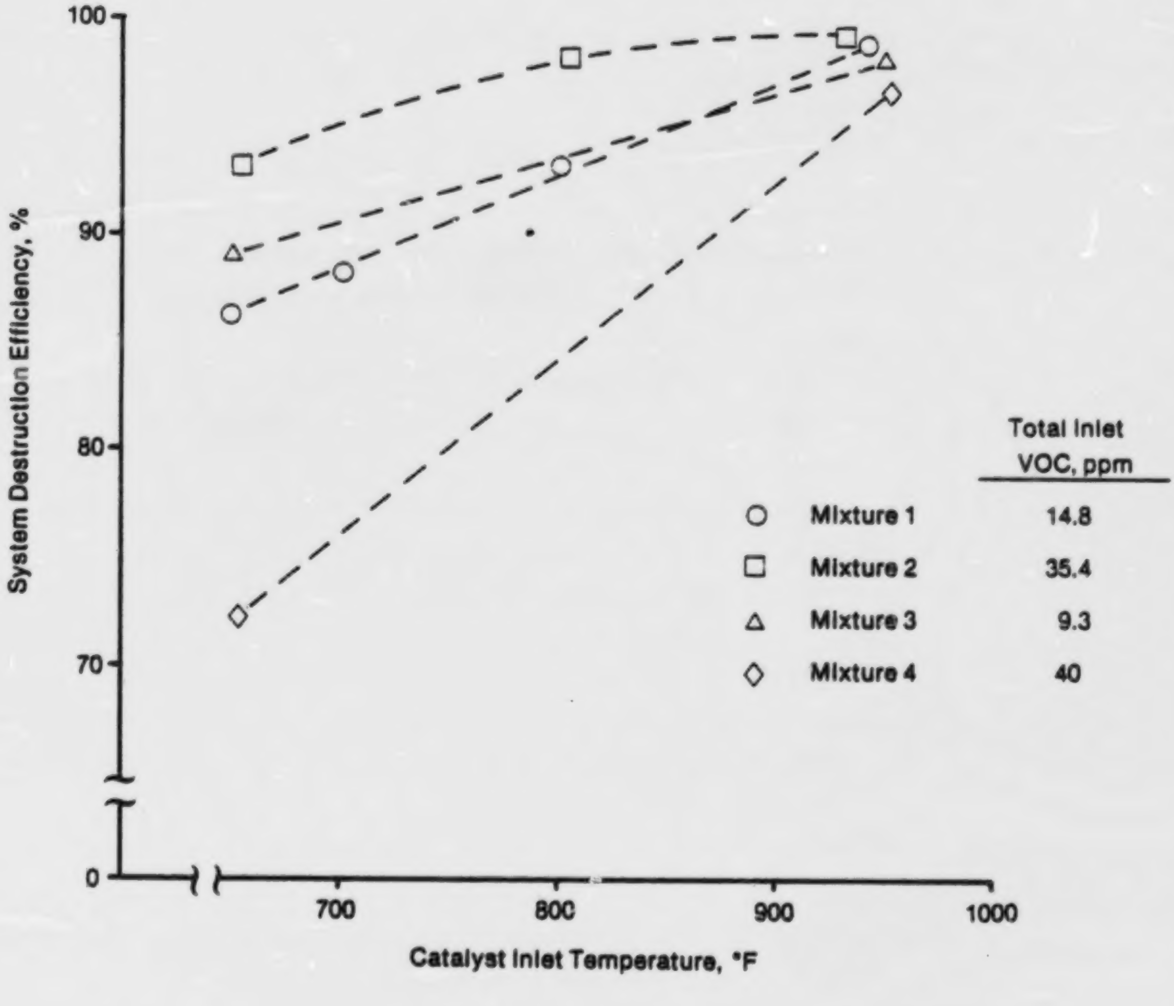

Figure 2-1. System Destruction Efficiencies As A Function Of Catalyst Inlet Temperature For All Mixtures At A Space Velocity of 10,500 $hr^{-1}$.

Destruction efficiency across the gas-fired preheater generally ranged from 15 to 55 percent for Mixtures 1, 3, and 4, which contained only chlorinated hydrocarbons. Heater destruction efficiencies for Mixture 2 were slightly higher, ranging from 40 to 60 percent.

Other results from the fluidized-bed incinerator testing included the following:

- Low concentrations of several chlorinated products of incomplete oxidation were identified by mass spectrometry.
- Incinerator outlet CO concentrations were less than 100 ppmv for most test conditions.
- No statistically significant effect was found for space velocity on destruction efficiency (although an apparent trend is seen when comparing mean values).
- Inlet concentration had no effect on Mixture 4 destruction efficiency over the range tested.
- Method 18 and the tenax-GC sampling method destruction efficiencies showed good agreement for all species and mixtures, with the exception of benzene in Mixture 2.
- Maximum theoretical HCl emissions from Mixtures 1, 2, and 3 were estimated to range from 0.06 to 0.3 lb/hr (6.3 to 28 ppmv) for a 1,000 scfm inlet gas stream.

## UV-Oxidizer Results

Test results for the UV-catalytic system without ozone showed total VOC destruction efficiencies ranging from 16 to 67 percent. The single most important parameter affecting destruction efficiency was space velocity and the highest efficiencies were observed at a space velocity of 200 $hr^{-1}$ (or a residence time of 18 seconds).

With ozone addition, complete oxidation of the test mixture components was achieved, but high concentrations of several unidentified reaction products was observed. Two of these products were identified by mass spectrometry as methyl formate and methyl acetate.

## Conclusions

The fluidized-bed incinerator testing verified that overall destruction efficiencies of total VOC's in the 97 to 98 percent range are achievable with catalytic incineration for chlorinated hydrocarbon mixtures. Results from this testing also indicate that catalytic incineration may be a viable option for the control of VOC/HAP emissions from groundwater air strippers.

The UV-catalytic oxidizer testing showed that unreasonably long gas residence times are required to achieve acceptable destruction without ozone addition and that high concentrations of reaction products are observed with ozone addition for this system. At this time, the UV-catalytic oxidizer would not be considered appropriate for controlling VOC/HAP emissions.

# 3.0 TEST SYSTEM DESCRIPTIONS

The destruction efficiencies of two different skid-mounted catalytic systems were measured during this test program. One system was a fluidized-bed catalytic incinerator with a natural gas-fired preheater. The other was an ultraviolet light (UV)-catalytic oxidizer operated near ambient temperatures. Test mixtures were generated by vaporizing liquid mixtures into an ambient air stream at a controlled rate. The fluidized-bed system is described in Section 3.1 and the UV-catalytic system is described in Section 3.2. The vapor generation systems were similar for each test unit and are described in Section 3.3.

## 3.1 FLUIDIZED-BED CATALYTIC INCINERATOR SYSTEM DESCRIPTION

A schematic diagram of the fluidized-bed catalytic incinerator, which was leased from ARI Internaional, is shown in Figure 3-1. Ambient air spiked with VOC/HAP test mixtures was blown into the incinerator by a 500 scfm (nominal) inlet air blower. The gases entered the preheater section of the incinerator perpendicular to a natural gas flame and were heated to a desired catalyst inlet temperature. Prior to entering the catalyst bed, the preheated gases flowed through a baffled grate and a non-fluidized bed of alumina balls. Test compounds were oxidized on the fluidized catalyst and exhaust gas was vented through a stack. A separate blower supplied combustion air for the natural gas burner.

Total inlet gas flow to the incinerator was controlled by a butterfly damper located at the blower inlet. The range of gas flowrates that could be tested with the incinerator was limited by: (1) the size of the blower and (2) the need to maintain fluidization of the catalyst. Inlet gas flowrates ranging from 300 to 500 scfm were tested.

The proprietary metal oxide catalyst was coated on spherical pellets of aluminum oxide. The non-fluidized catalyst volume was 2.85 $ft^3$, giving a space velocity of 10,500 $hr^{-1}$ at an inlet gas flowrate of 500 scfm. The fluidized bed volume and bed depth were approximately 5 $ft^3$ and 16 inches, respectively.

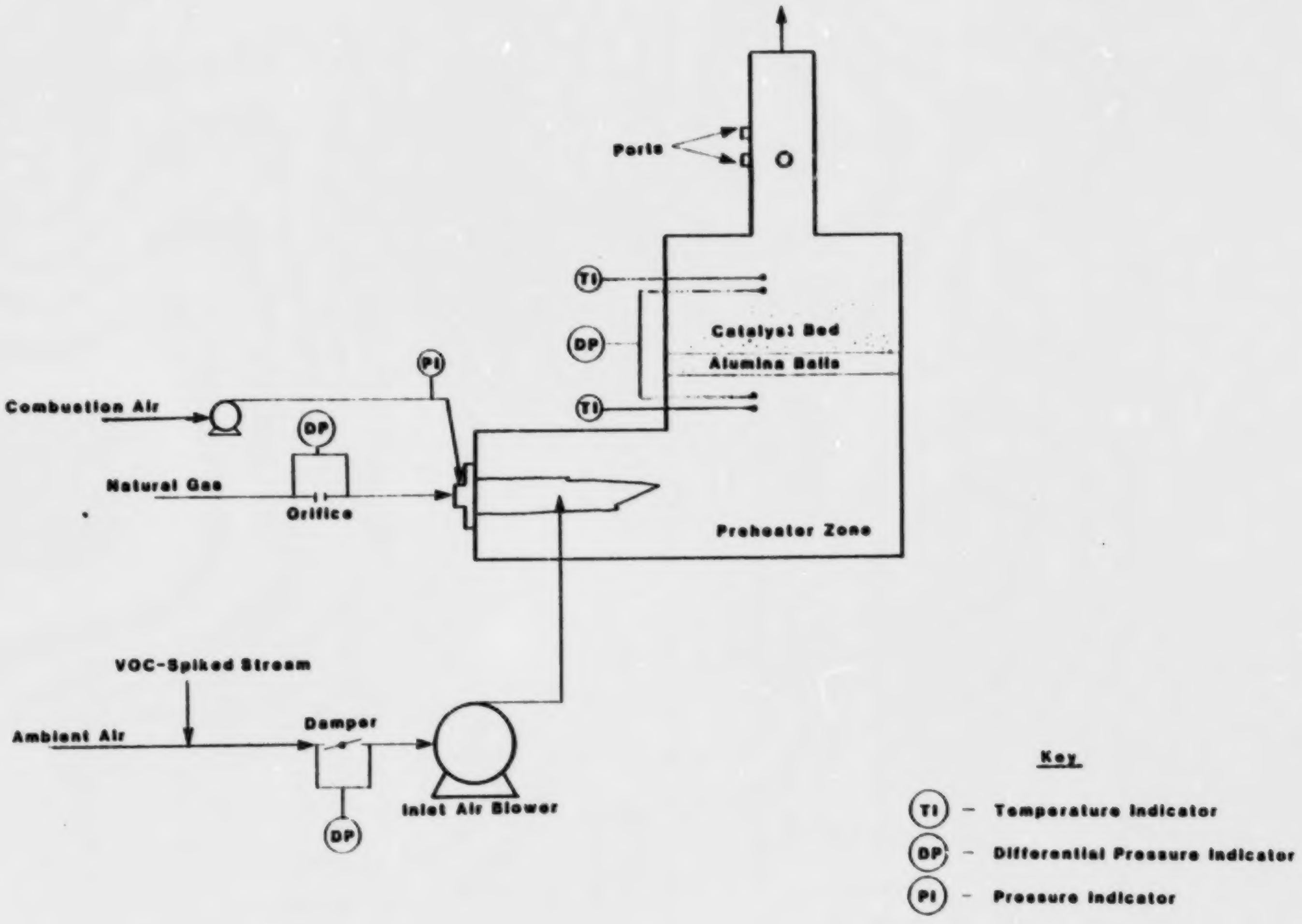
Ports
Catalyst Bed
Alumina Balls
Preheater Zone
TI
DP
TI
PI
Combustion Air
DP
Natural Gas
Orifice
VOC-Spiked Stream
Ambient Air
Damper
DP
Inlet Air Blower
Key
TI – Temperature Indicator
DP – Differential Pressure Indicator
PI – Pressure Indicator

Figure 3-1. Fluidized-Bed Catalytic Incinerator System.

Instrumentation on the pilot incinerator included a controller for the catalyst inlet temperature. This controller adjusted both the natural gas and combustion air flowrates to maintain the desired temperature. For different test conditions, manual re-adjustment of the ratio of combustion air to natural gas (air-to-gas ratio, scf/scf) was necessary. Throughtout the test program a target air-to-gas ratio of 20:1 (approximately 100 percent excess air) was used. The natural gas burner had a design rating of 1 million Btu/hr. During the test program, the burner operated between 0.5 and 0.7 million Btu/hr.

Other instrumentation on the pilot test unit included indicators for catalyst outlet temperature, combustion air pressure, and natural gas orifice and catalyst bed pressure drops. Automatic shutdown mechanisms were also included for blower failures, natural gas loss, and temperature excursions.

The preheater and catalyst zones of the incinerator were refractory lined but included no external insulation. Temperature drops ranging from 15° to 40°F were typically observed across the catalyst, depending on the catalyst inlet and the ambient temperatures.

## 3.2 UV-CATALYTIC SYSTEM

The ultraviolet (UV)-catalytic test unit was part of a complete pilot-scale water treatment system that consisted of an ozone generator, a water-phase UV reaction tank, and a gas-phase UV-catalytic reactor. Only the gas-phase reactor was tested during this program.

A diagram of the entire skid-mounted pilot unit, which was leased from Ultrox International (Culver City, CA), is shown in Figure 3-2. When used for water treatment, ground water contaminated with chlorinated hydrocarbons is pumped into the reaction tank where an ozone/air mixture is bubbled through the water and the water is irradiated with UV light. Hydrocarbons in the water are oxidized by the UV and ozone to form carbon dioxide, water, and hydrochloric acid (HCl). A portion of the hydrocarbons are "stripped" from the water by the ozone/air mixture and this gas stream passes into the

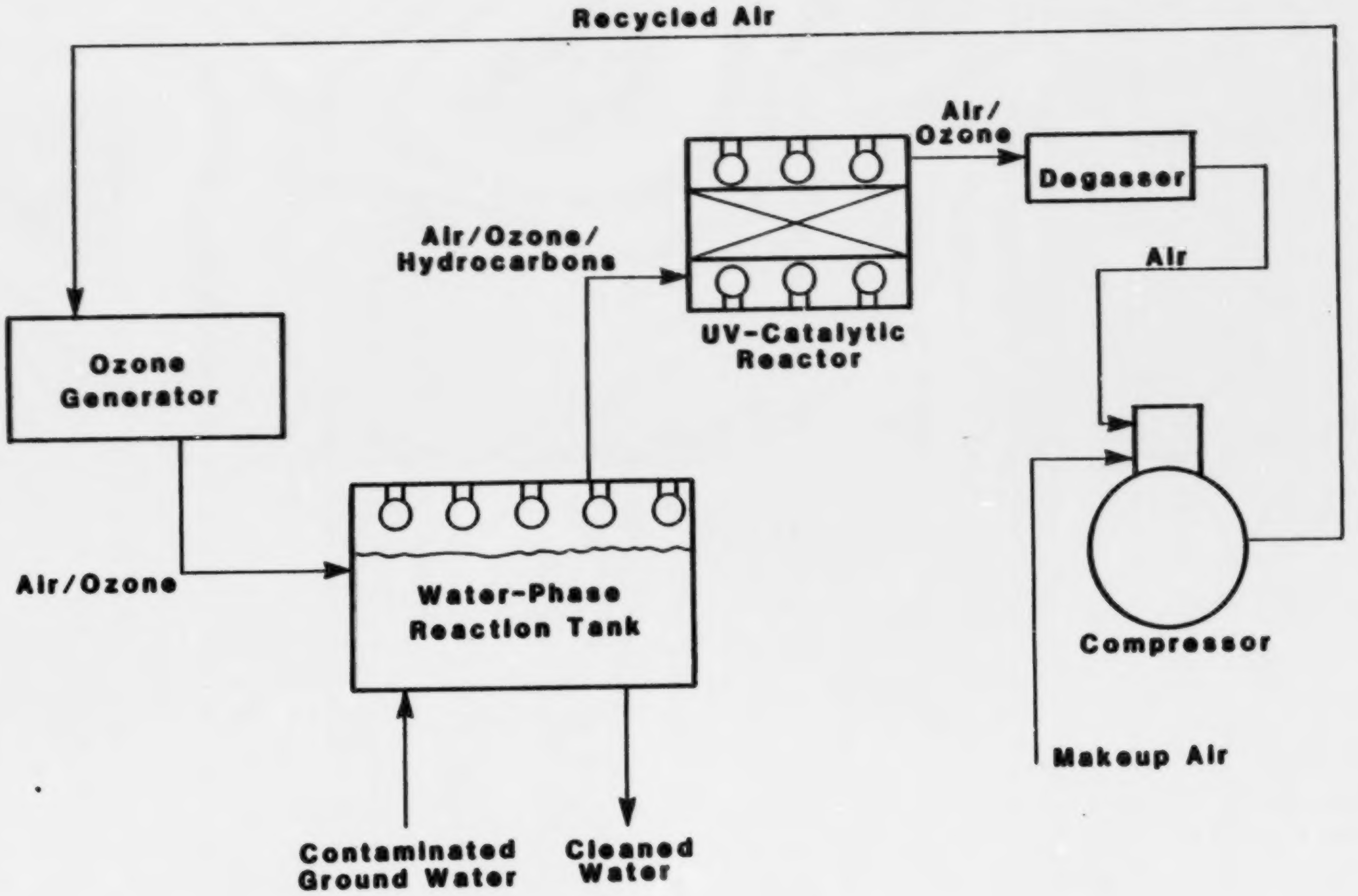
Recycled Air
Air/
Ozone
Degasser
Air/Ozone/
Hydrocarbons
Air
Ozone
Generator
UV-Catalytic
Reactor
Air/Ozone
Water-Phase
Reaction Tank
Compressor
Makeup Air
Contaminated
Ground Water
Cleaned
Water

Figure 3-2. Schematic Diagram of Pilot-Scale UV-Catalytic Test System.

UV-catalytic reactor. Further oxidation of the hydrocarbons occurs in the reactor and the exit gases enter a degasser unit which destroys any ozone remaining in the air. The air is then pumped back to the ozone generator by a compressor so that no gases are vented directly to the atmosphere. The UV-catalytic reactor operates at ambient temperatures (70 to 100°F) and heat generated in the reactor by UV lamps is removed by a pre-cooled stream of air or nitrogen (not shown in Figure 3-2).

During this test program, contaminated air streams were passed through the gas-phase reactor to determine VOC/HAP destruction efficiencies. The air streams were passed into the UV-catalytic reactor at the connection between the reactor and water-phase reaction tank. The reactor contained UV lamps with a specific wave-length and a proprietary heterogeneous catalyst. The reported design flowrate of the reactor was 10 to 20 scfm for the compounds and concentrations of interest. The effective volume of the fixed bed reactor was 0.3 $ft^3$, giving a space velocity of 3,000 $hr^{-1}$ at 15 acfm.

## 3.3 TEST MIXTURE VAPOR GENERATION SYSTEM

The test mixture vapor generation system provided VOC/HAP-spiked air streams for measurement of destruction efficiency. The vapor generation system used for the UV-catalytic oxidizer was a simplified version of the generation system used for the fluidized-bed incinerator.

A schematic of the test mixture vapor generation system for the fluidized-bed catalytic incinerator is shown in Figure 3-3. This system began with a Dayton Model 42469 rotary vane pump which provided the gas for vaporizing and carrying the solvents to the incinerator inlet duct. This pump was capable of pumping ambient air into the system at a flowrate of 15 acfm.

Gas exiting the pump was heated by two methods. Heating tapes powered by variable transformers heated all exposed tubing and pipe from just beyond the pump to the incinerator inlet duct. In addition, a resistance-type tube furnace was used to provide additional heat to the section of piping just upstream of the points of solvent injection. The gas temperature at the solvent injection point was maintained above 200°F.

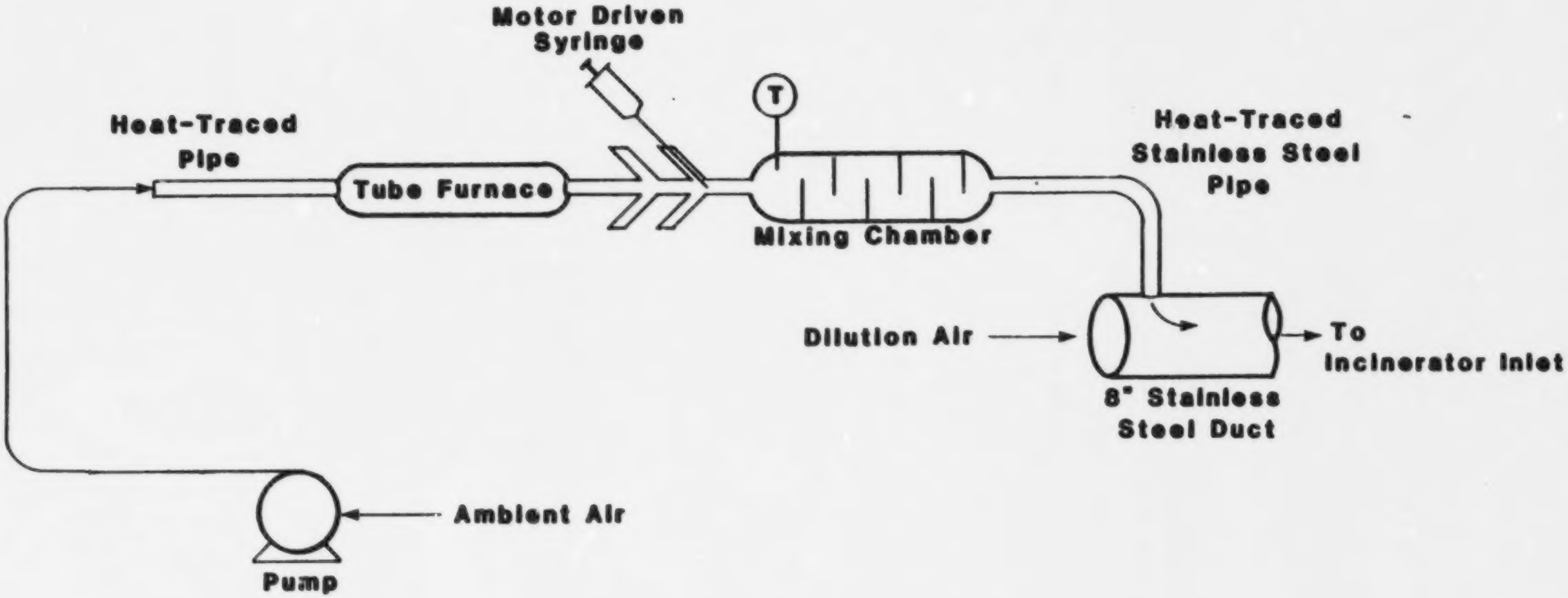
Motor Driven Syringe
Heat-Traced Pipe
Tube Furnace
T
Mixing Chamber
Heat-Traced Stainless Steel Pipe
Dilution Air
To Incinerator Inlet
8" Stainless Steel Duct
Ambient Air
Pump

Figure 3-3. Test Mixture Vapor Generation System For Fluidized-Bed Catalytic Incinerator.

The solvent injection, vaporization, and mixing all occurred in a custom-made glass unit. The unit contained four 1/4" o.d. solvent injection ports set into a 1/2" o.d. inlet at a 45° angle. This injection design was believed to prevent blowback of solvent into the injection ports. The injection ports were sealed with Swagelok$^R$ unions containing septa in the nut. Solvent was injected into the systems by inserting the hypodermic needle attached to a syringe through the septum such that the tip of the needle was at the middle of the inlet tube which carries the gas into the mixing chamber.

Two motor-driven syringe pumps were used to drive liquid VOC/HAP mixtures through 50 mL syringes and into the system: a Sage Instruments Model 341 pump and a Harvard Model 975 pump. After the liquid entered the system it flash vaporized in the heated air stream and was immediately delivered to the mixing chamber to produce a homogeneous mixture. The stream then flowed through heat-traced stainless steel pipe until it entered the 10 foot long, 8 inch diameter blower inlet duct.

For the test conditions where liquid injection rates of over 2 ml/min were required, the syringes were replaced by another liquid feed system which is shown in Figure 3-4. This feed system consisted of a stainless steel pressure vessel, a metering valve, a liquid flowmeter, and 1/16 inch diameter needle tubing. As shown in Figure 3-4, the needle tubing was inserted into the septum in the same manner as the syringe needles. By placing the system under pressure from a nitrogen tank, the liquid test mixtures were injected into the gas stream. The pressurized feed system was used for liquid flowrates of approximately 12 ml/min.

The UV-catalytic oxidizer used a similar test mixture vapor generation system. Modifications made for the UV-catalytic oxidizer testing included: (1) use of a slipstream vaporization system, (2) addition of a dry gas meter and a Rootsmeter$^R$ for gas flowrate measurement, and (3) elimination of most heating tapes and the tube furnace.

The vapor generation system as modified for the UV-catalytic oxidizer is shown in Figure 3-5. Test mixtures were vaporized in this system using a small heat-traced glass tube and a heated-head pump that provided a 4 ml/min

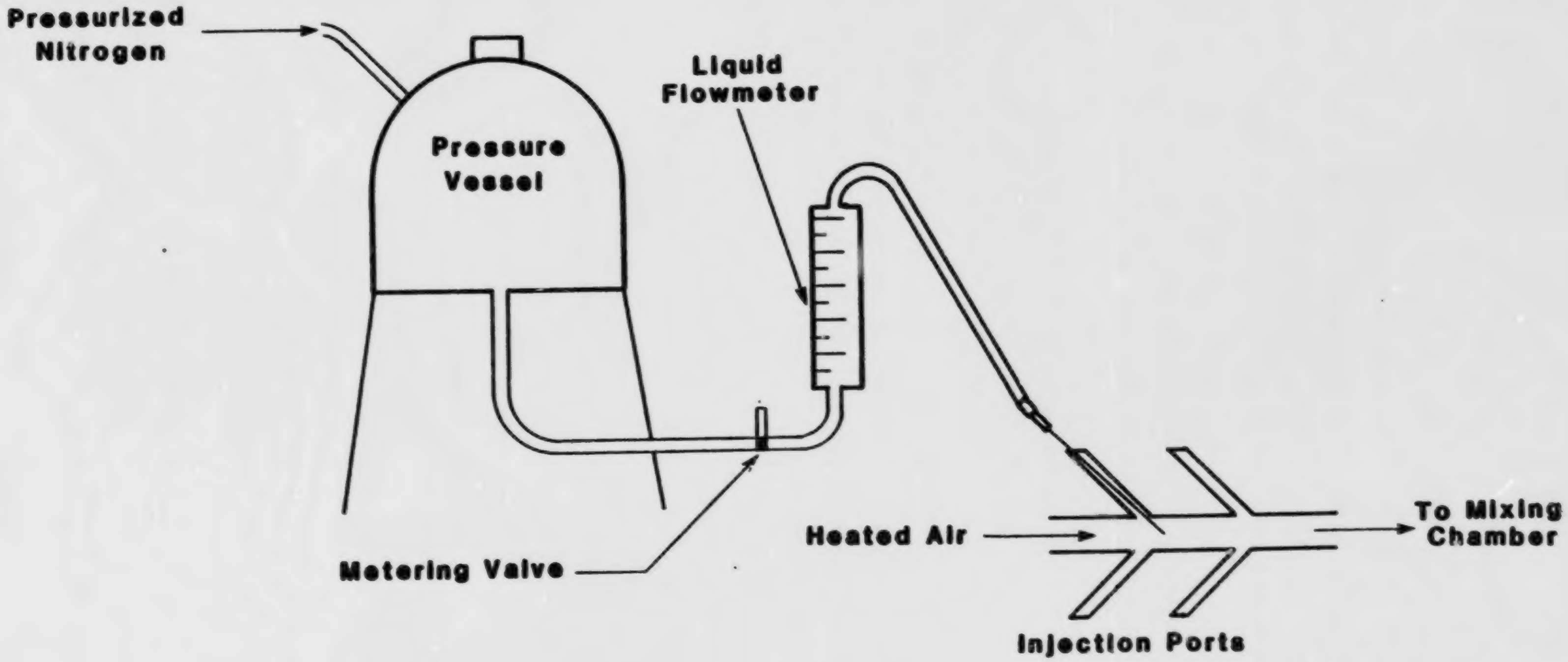
Pressurized Nitrogen
Pressure Vessel
Liquid Flowmeter
Metering Valve
Heated Air
Injection Ports
To Mixing Chamber

Figure 3-4. High Volume Liquid Feed System.

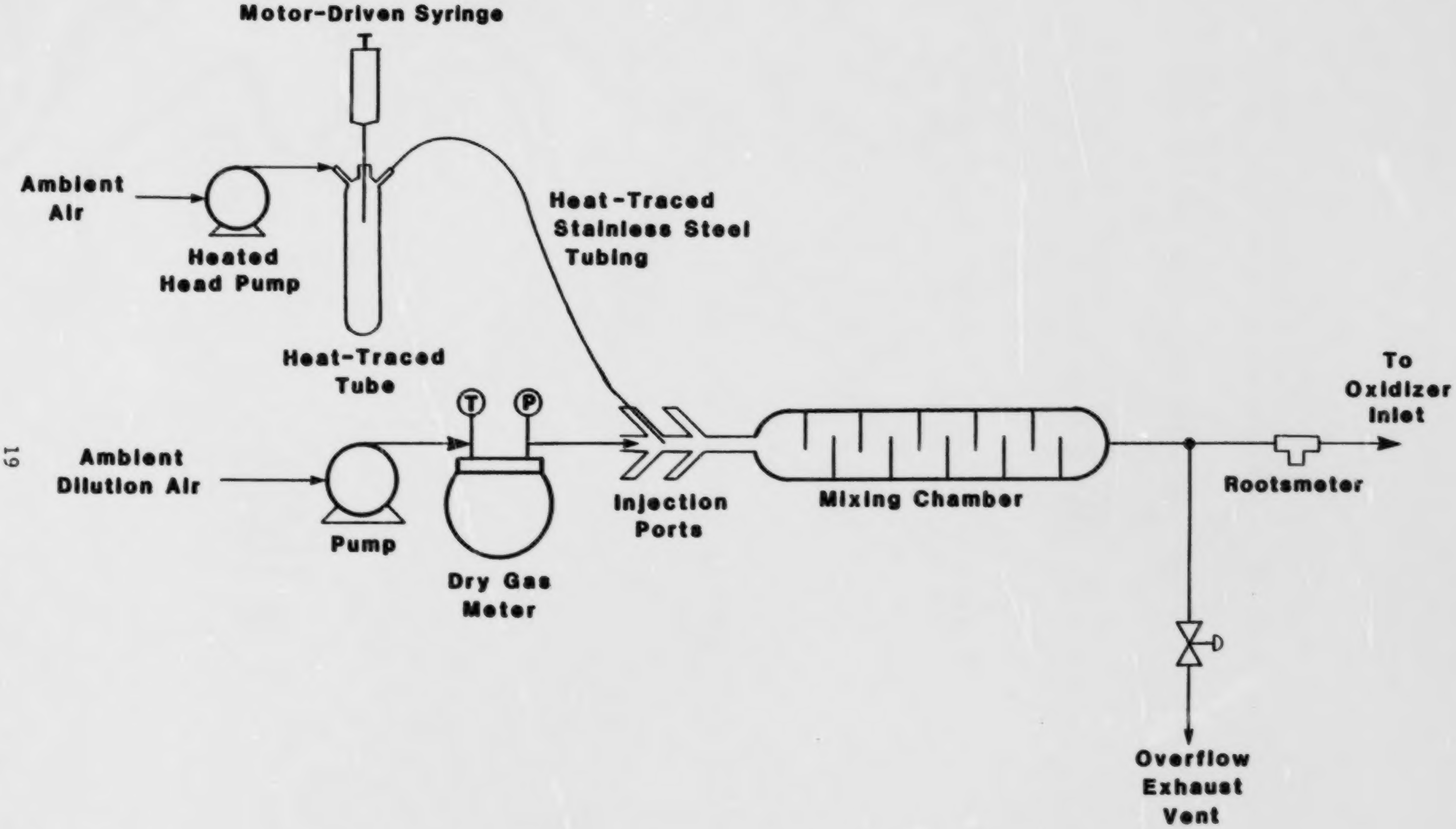
Motor-Driven Syringe
Ambient Air
Heated Head Pump
Heat-Traced Tube
Heat-Traced Stainless Steel Tubing
Ambient Dilution Air
Pump
T
P
Dry Gas Meter
Injection Ports
Mixing Chamber
Rootsmeter
To Oxidizer Inlet
Overflow Exhaust Vent

Figure 3-5. Test Mixture Vapor Generation System For UV-Catalytic Oxidizer.

slipstream. A motor-driven syringe pump and a glass mixing chamber were used as in the previous system. As discussed in Section 3.2, the UV-catalytic oxidizer operated near ambient temperatures. Use of the slipstream vaporization system and elimination of other heating tape and the tube furnace provided an ambient temperature gas stream for this testing.

A 17 acfm capacity Sprage Meter Company dry gas meter was used to measure gas flowrates through the vapor generation system. Downstream of the glass mixing chamber, the spiked air stream was split between an overflow exhaust vent and the oxidizer inlet. The oxidizer inlet gas flowrate was measured using a Rootsmeter$^R$ or lobed-impeller flowmeter. Temperature and pressures at the dry gas meter and the Rootsmeter$^R$ were measured with thermocouples/digital readouts and Magnehelic$^R$ gauges, respectively.

## 4.0 EXPERIMENTAL DESIGN

The technical objective of this program was to investigate, on an experimental scale, the effectiveness of catalytic oxidation as a means of destroying specific volatile organic compounds (VOC) and hazardous air pollutants (HAP). To achieve this objective, major vendors of catalytic oxidation systems were contacted to (1) investigate the availability of catalysts and catalytic systems suitable for destroying chlorinated hydrocarbons and (2) identify those vendors with existing laboratory- or pilot-scale units that could be tested under this program. The result of this effort was the identification of two available systems: a fluidized-bed catalytic incinerator and a UV-catalytic oxidizer.*

Major operating parameters that were varied during the fluidized-bed incinerator testing included VOC/HAP mixture, catalyst inlet temperature, space velocity, and inlet concentration. Testing was generally conducted to characterize destruction across the gas-fired preheater and catalyst bed as a "system". However, heater and catalyst destruction efficiencies were also determined separately at most test conditions. In all cases, both total mixture and individual species destruction efficiencies were determined.

Operating parameters that were varied during the UV-catalytic oxidizer testing included space velocity, inlet concentration, UV intensity, humidity, and ozone addition.

### 4.1 TEST PARAMETERS

Parameters and conditions tested for each of the two catalytic oxidation systems are discussed separately in the sections below.

---

*A fixed bed noble metal catalyst system was tested previously (Reference 1).

## Fluidized Bed System

Test parameters and conditions for the fluidized bed system are shown in Table 4-1. A total of ten compounds in four VOC mixtures were tested. Compounds in each of the four mixtures are shown in Table 4-2. The first three mixtures, Mixtures 1, 2, and 3, were selected as representative of gas streams from air strippers used for groundwater cleanup. Mixture 4 was selected simply to provide data on additional chlorinated species. Since trichloroethylene was present in all four mixtures, the effect of mixture composition on compound specific destruction was assessed for trichloroethylene.

Space velocities, based on the unfluidized catalyst volume and standard inlet gas flowrates, were tested at 7,000 and 10,500 $hr^{-1}$. Catalyst inlet temperatures were varied from 650°C to 950°F.

## UV-Catalytic System

Conditions tested with the UV-catalytic oxidizer are shown in Table 4-3. The original test plan called for testing of this system to assess the effects of mixture, space velocity, catalyst temperature, humidity, inlet concentration, and UV intensity on destruction efficiency. No plans for the use of ozone in the reactor were included.

Ultimately, only one of the four mixtures, Mixture 1, was tested using the UV-catalytic system and several tests were conducted with ozone addition. As will be discussed further in Section 7.0, destruction efficiencies observed for Mixture 1 without ozone were below desired levels and high concentrations of several unidentified reaction products were observed with ozone. These findings led to a decision to discontinue testing of the UV-catalytic system.

Space velocities tested with the UV-catalytic oxidizer included 200, 800, and 3000 $hr^{-1}$. Inlet concentration was tested at and below the baseline level and tests were also conducted at higher than ambient humidity.

TABLE 4-1. TEST PARAMETERS AND CONDITIONS FOR FLUIDIZED BED CATALYTIC INCINERATOR

| Test Parameter | Conditions or Values Tested |
|---|---|
| VOC/HAP Mixture | Mixtures 1, 2, 3, and 4[a] |
| Space Velocity[b] | 10,500 $hr^{-1}$ (500 scfm)<br>7,000 $hr^{-1}$ (330 scfm) |
| Inlet Concentration | Baseline[a]<br>High |
| Operating Temperature<br>(Catalyst Inlet) | 650°F<br>700°F<br>800°F<br>950°F |

[a] Mixtures and concentrations are summarized in Table 4-2.

[b] Space velocity based on unfluidized catalyst volume and the inlet gas flow rate at standard conditions (68°F, 14.7 psia).

## TABLE 4-2. MIXTURE COMPOSITIONS AND TARGET CONCENTRATIONS FOR CATALYTIC OXIDATION TESTS

| Mixture Designation | Concentration Level | Mixture Compounds | Target Inlet Concentration (ppmv) |
|---|---|---|---|
| Mixture 1 | Baseline | Trichloroethylene | 6.3 |
| | | 1,2 dichloroethylene | 8.5 |
| Mixture 1 | Low | Trichloroethylene | 1.9 |
| | | 1,2 dichloroethylene | 1.0 |
| Mixture 2 | Baseline | Trichloroethylene | 2.7 |
| | | Benzene | 1.5 |
| | | Ethylbenzene | 5.6 |
| | | Pentane | 11.5 |
| | | Cyclohexane | 14.1 |
| Mixture 3 | Baseline | Vinyl chloride | 7.5 |
| | | Trichloroethylene | 1.8 |
| Mixture 4 | Baseline | 1,2 dichloroethane | 10 |
| | | Trichloroethylene | 10 |
| | | 1,1,2-trichloroethane | 10 |
| | | Tetrachloroethylene | 10 |
| Mixture 4 | High | 1,2 dichloroethane | 50 |
| | | Trichloroethylene | 50 |
| | | 1,1,2-trichloroethane | 50 |
| | | Tetrachloroethylene | 50 |

TABLE 4-3. TEST PARAMETERS AND CONDITIONS FOR UV-CATALYTIC OXIDIZER

| Test Parameter | Conditions or Values Tested |
|---|---|
| VOC/HAP Mixture | Mixture 1[a] |
| Space Velocity | 3,000 $hr^{-1}$ (15 scfm)<br>800 $hr^{-1}$ (4 scfm)<br>200 $hr^{-1}$ (1 scfm) |
| Inlet Concentration | Baseline[a]<br>Low |
| Operating Temperature | 90°F |
| Humidity | Ambient<br>150% of Ambient |
| UV Intensity | UV lamps on<br>UV lamps off |
| Ozone | Without ozone<br>With ozone |

[a] Mixtures and concentrations are summarized in Table 4-2.

[b] Space velocity based on UV-catalytic reactor volume of 0.3 $ft^3$ and inlet gas flow rate at standard conditions (68°F, 14.7 psia).

## 4.2 TEST MATRICES

The experimental portion of this program consisted of two test series. The matrices for these test series are summarized in Tables 4-4 and 4-5. Each test series is discussed in detail below.

### Test Series A

Test Series A was used to assess the effects of space velocity, inlet concentration, humidity, UV intensity and ozone addition on the oxidation efficiency of the UV-catalytic test system. Tests were conducted with one mixture at three space velocities, two humidity levels, two inlet concentrations, with and without ozone, and with and without UV lamps.

### Test Series B

This test series was designed to assess the effects of VOC/HAP mixture, space velocity, catalyst inlet temperature and inlet concentration on the destruction efficiency of the fluidized bed test system. Each of the four mixtures were tested at two space velocities and two or three inlet temperatures. Mixture 4 was also tested at two inlet concentrations. Replicate tests were performed for Mixtures 1, 2, and 4 to provide the between-run (i.e. run-to-run) precision estimate necessary to evaluate the statistical significance of any observed differences in destruction efficiencies.

TABLE 4-4. TEST MATRIX FOR THE UV-CATALYTIC OXIDIZER (SERIES A)

| Trial Number | Test Mixture | Catalyst Operating Temperature (°F) | Space Velocity ($hr^{-1}$) | Inlet Concentration | Humidity | UV Lamps | Ozone |
|---|---|---|---|---|---|---|---|
| A2[a] | 1 | 90 | 3,000 | Baseline | Ambient | On | Off |
| A3[a] | 1 | 90 | 3,000 | Baseline | Ambient | On | Off |
| A4[b] | 1 | 90 | 800 | Baseline | Ambient | On | Off |
| A5[b] | 1 | 90 | 800 | Baseline | Ambient | On | Off |
| A6[b] | 1 | 90 | 800 | Baseline | Ambient | On | Off |
| A7 | 1 | 90 | 800 | Baseline | 1.5 Ambient | On | Off |
| A8 | 1 | 90 | 800 | Low | 1.5 Ambient | On | Off |
| A9[c] | 1 | 90 | 800 | Baseline | 1.5 Ambient | On | Off |
| A10 | 1 | 90 | 200 | Low | 1.5 Ambient | On | Off |
| A12 | 1 | 90 | 800 | Baseline | 1.5 Ambient | On | On |
| A13 | 1 | 90 | 3,000 | Baseline | 1.5 Ambient | On | On |
| A14 | 1 | 90 | 3,000 | Baseline | 1.5 Ambient | Off | On |

[a] Test duplicates.

[b] Test replicates.

[c] Catalyst bed saturated with water prior to test.

## TABLE 4-5. TEST MATRIX FOR THE FLUIDIZED-BED CATALYTIC INCINERATOR (SERIES B)

| Test Number | Test Mixture | Inlet Concentration | Space Velocity (hr$^{-1}$) | Catalyst Operating Temperature (°F) |
|---|---|---|---|---|
| B1 | 1 | Baseline | 10,500 | 700 |
| B2 | 1 | Baseline | 7,000 | 700 |
| B3 | 1 | Baseline | 10,500 | 700 |
| B4[a] | 1 | Baseline | 10,500 | 800 |
| B5 | 1 | Baseline | 7,000 | 800 |
| B6 | 1 | Baseline | 7,000 | 950 |
| B7 | 1 | Baseline | 10,500 | 950 |
| B8[b] | 2 | Baseline | 10,500 | 800 |
| B9 | 2 | Baseline | 7,000 | 650 |
| B10 | 2 | Baseline | 10,500 | 650 |
| B11 | 2 | Baseline | 7,000 | 800 |
| B12 | 2 | Baseline | 7,000 | 950 |
| B13 | 2 | Baseline | 10,500 | 950 |
| B14[b] | 2 | Baseline | 10,500 | 800 |
| B15[a] | 1 | Baseline | 10,500 | 800 |
| B16[c] | 4 | Baseline | 7,000 | 650 |
| B17 | 4 | Baseline | 10,500 | 650 |
| B18 | 4 | Baseline | 7,000 | 950 |
| B19 | 4 | Baseline | 10,500 | 950 |
| B20[c] | 4 | Baseline | 7,000 | 650 |
| B22 | 4 | High | 10,500 | 660 |
| B23 | 4 | High | 10,500 | 950 |
| B24 | 4 | High | 7,000 | 950 |
| B25 | 3 | Baseline | 7,000 | 650 |
| B26 | 3 | Baseline | 10,500 | 650 |
| B27 | 3 | Baseline | 7,000 | 800 |
| B28 | 3 | Baseline | 10,500 | 950 |
| B29[a] | 1 | Baseline | 10,500 | 800 |

[a] Control test replicates for Mixture 1.

[b] Control test duplicates for Mixture 2.

[c] Control test duplicates for Mixture 4.

# 5.0 SAMPLING SYSTEMS AND ANALYTICAL PROCEDURES

Sampling and analytical procedures used to characterize performance of the catalytic test systems included methods for determining VOC/HAP concentrations and compositions, carbon monoxide (CO) concentrations, gas flowrates, temperatures, pressures and humidity. A summary of the sampling and analytical methods used is shown in Table 5-1. These sampling and analytical methods are discussed separately in Sections 5.1 and 5.2, respectively.

## 5.1 SAMPLING PROCEDURES

As shown in Table 5-1, many of the same sampling methods were used for both the fluidized-bed incinerator and the UV-oxidizer. The VOC/HAP samples for Method 18 were withdrawn through stainless steel probes using heated-head pumps that were located as close to the sampling point as possible. The sample was then blown through a heat-traced teflon line that was maintained at or above 220°F.

The sample for determining carbon monoxide (CO) concentrations was drawn from the outlet of the catalytic reactor or the catalyst bed by a pump inside the CO analyzer. The sample was filtered and drawn through an unheated teflon line, an empty impinger for water knockout, and a silica gel impinger to dry the gas before it entered the instrument.

Gas stream temperatures were monitored using thermocouples and calibrated digital readouts. Pressures were measured with either Magnehelic$^R$ gauges or gauge oil manometers and humidity was determined using a pychrometer.

Procedures that differ for the two test units include the number and types of VOC/HAP samples collected, the use of a tenax-GC sampling procedure for the fluidized-bed system, and methods used for determining volumetric gas flowrates. Specifics on these procedures are provided in Sections 5.1.1 and 5.1.2.

TABLE 5-1. SUMMARY OF SAMPLING AND ANALYTICAL METHODS

| Parameter | Catalytic Test System | Sampling Method | Analytical Method |
|---|---|---|---|
| VOC/HAP Concentration | Fluidized-bed and UV-Oxidizer | Stainless steel probe, heated-head pump, and heated teflon sample line | Method 18 (GC/FID)[a] |
|  | Fluidized-bed | Tenax-GC resin sampling train | GC/FID |
| VOC/HAP Composition | Fluidized-bed | Tenax-GC resin sampling train | GC/MS[b] |
| Carbon Monoxide Concentration | Fluidized-bed and UV-oxidizer | Teflon sample line | Infrared analyzer |
| Volumetric Flowrates | Fluidized-bed | Method 2 | - |
|  | UV-Oxidizer | Dry gas meter and rootsmeter | - |
| Temperature | Fluidized-bed and UV-Oxidizer | Thermocouple/digital readout | - |
| Pressure | Fluidized-bed and UV-Oxidizer | Magnehelic gauges and oil manometers | - |
| Humidity | Fluidized-bed and UV-Oxidizer | Psychrometer | - |

[a] GC/FID is gas chromatography/flame ionization detector.

[b] GC/MS is gas chromatography/mass spectrometry.

### 5.1.1 Fluidized-Bed Catalytic Incinerator

A diagram of the sampling system for the fluidized-bed catalytic incinerator is shown in Figure 5-1. Samples to be analyzed for VOC/HAP concentration were collected at three locations: the preheater inlet, the catalyst bed inlet, and the catalyst bed outlet. The preheater inlet sample was collected between the blower outlet and the burner, the catalyst bed inlet sample was collected just under the catalyst bed grate, and the catalyst bed outlet sample was collected from the system exhaust stack. The VOC/HAP concentrations at all three sample locations were determined by Method 18. In cases where the outlet concentrations were at or below 1 ppmv, a tenax-GC sampling procedure was also used. Procedures used for collecting the tenax-GC sample and for determining gas flowrates at the incinerator inlet and outlet are discussed in the sections below.

#### Tenax-GC Sampling Procedures

A diagram of the tenax-GC sampling train is shown in Figure 5-2. An integrated gas sample was withdrawn from the outlet stack through a stainless steel probe. The stack gas was cooled to 68°F or lower in a water-cooled glass condenser before VOC/HAP present in the gas were collected in a stainless steel tenax-GC resin trap. Moisture remaining in the gas was removed by a silica gel impinger before the gas entered a meter box containing a rotameter, pump and dry gas meter.

The tenax-GC resin traps were made from 4-inch long, 0.5-inch diameter stainless steel tubing. For most test mixtures, the traps contained approximately 1.5 grams of tenax-GC resin. Traps containing 1 gram of tenax-GC and 1 gram of activated charcoal were used for the test mixture that contained vinyl chloride.

For each test condition requiring tenax-GC sampling, four tenax-GC samples were collected. The outlet stack gas was sampled at a rate of 0.5 liters/min for 3 to 8 minutes per trap. A targeted collection of 1,000 to 3,000 ng of each VOC or HAP was used to calculate the sampling times. A daily field blank was also collected. Sample train leak checks were performed for each set of four traps and meter volumes, temperatures, and pressures were recorded for each trap. The traps were sealed in plastic bags and stored in coolers except during use.

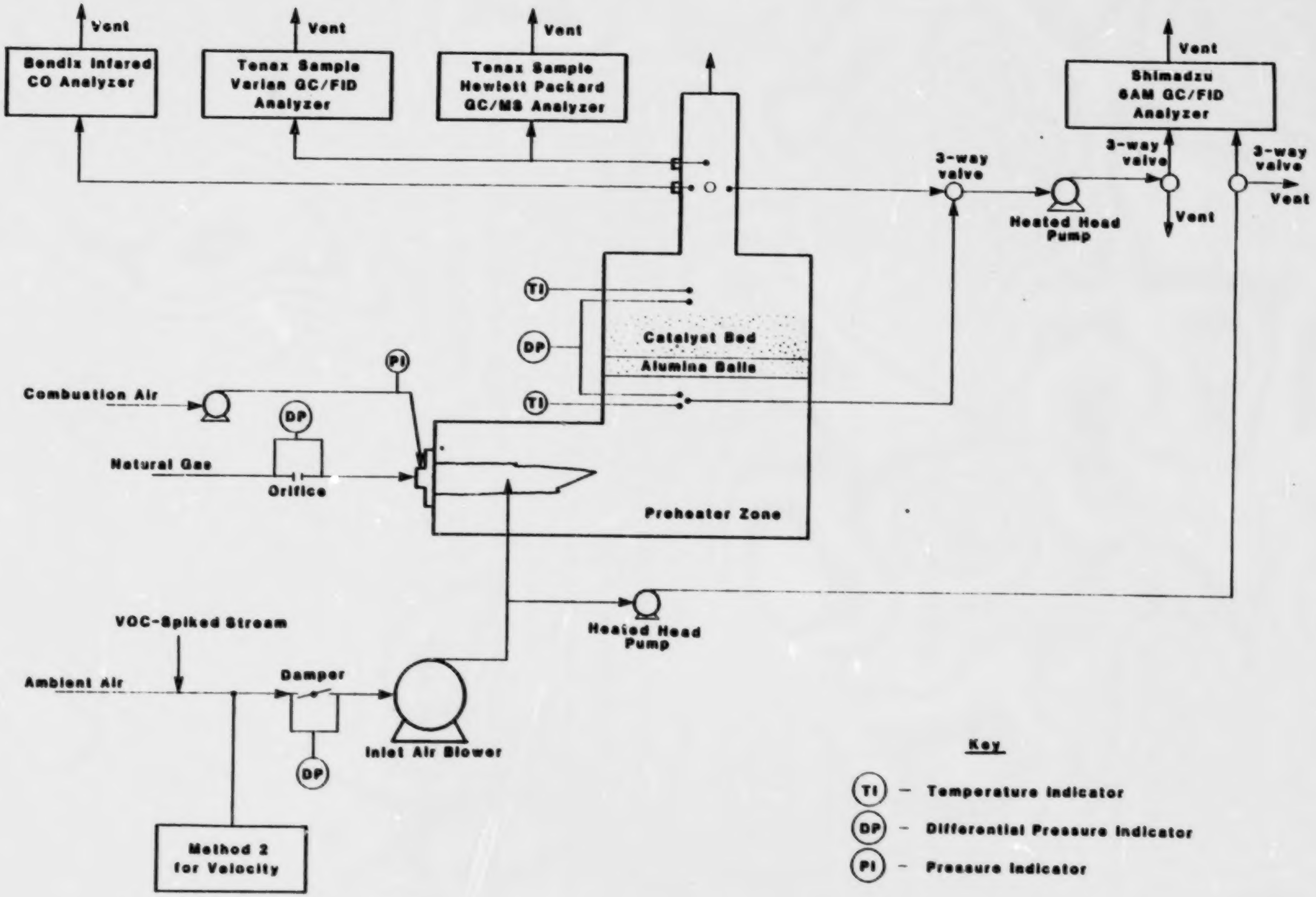
Vent
Bendix Infared CO Analyzer
Vent
Tenax Sample Varian GC/FID Analyzer
Vent
Tenax Sample Hewlett Packard GC/MS Analyzer
Vent
Shimadzu 6AM GC/FID Analyzer
3-way valve
3-way valve
3-way valve
Vent
Vent
Heated Head Pump
TI
DP
TI
Catalyst Bed
Alumina Balls
PI
Combustion Air
DP
Natural Gas
Orifice
Preheater Zone
Heated Head Pump
VOC-Spiked Stream
Ambient Air
Damper
DP
Inlet Air Blower
Method 2 for Velocity
Key
TI – Temperature Indicator
DP – Differential Pressure Indicator
PI – Pressure Indicator

Figure 5-1. Sampling Diagram For Fluidized-Bed Catalytic Incinerator.

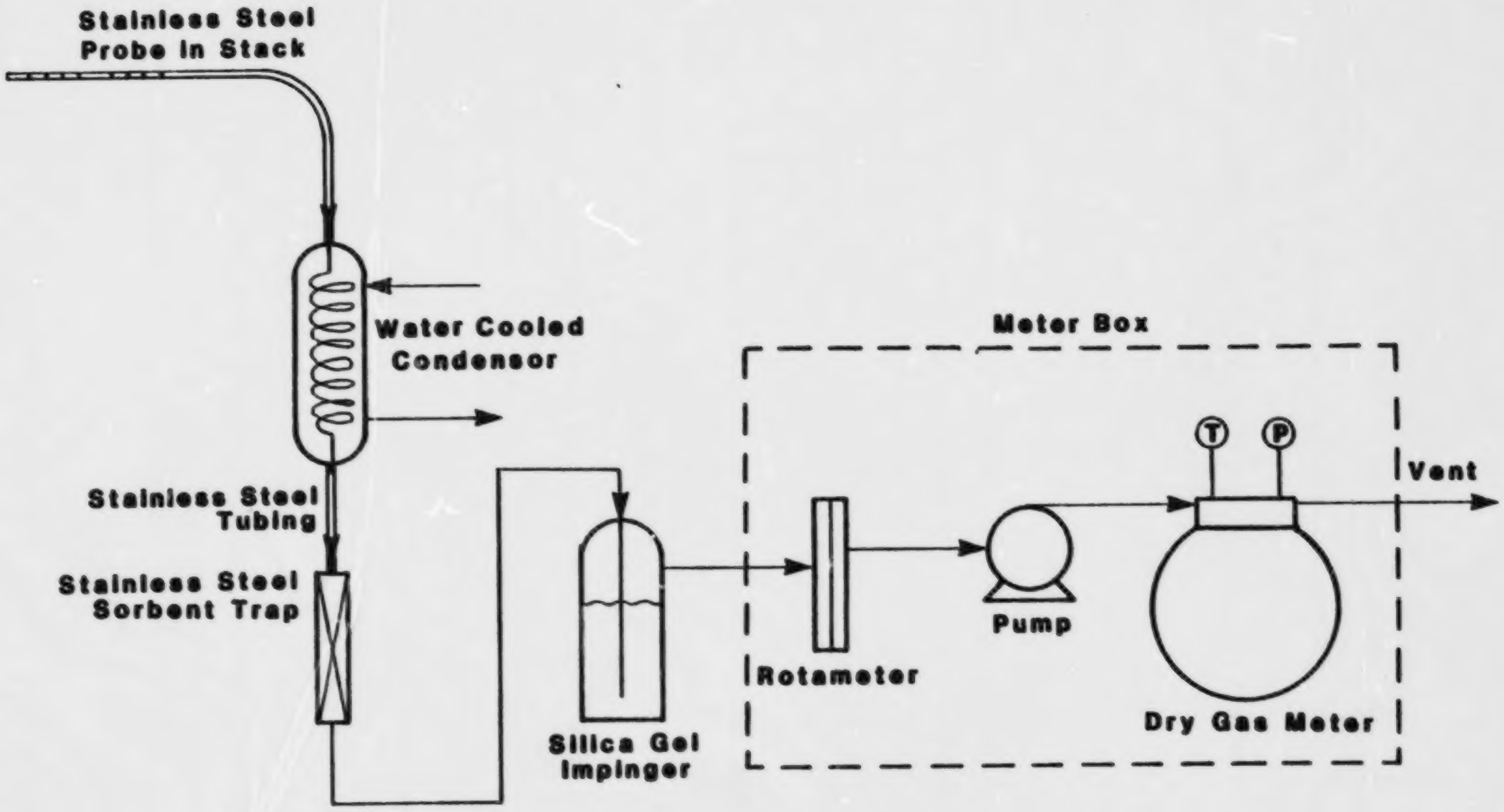
Stainless Steel Probe in Stack
Water Cooled Condensor
Stainless Steel Tubing
Stainless Steel Sorbent Trap
Silica Gel Impinger
Meter Box
Rotameter
Pump
T
P
Dry Gas Meter
Vent

Figure 5-2. Tenax-GC Resin Sampling Train.

### Volumetric Gas Flowrates

Volumetric gas flowrates were determined at the blower inlet and the outlet stack using EPA Method 2. In this method, the volumetric gas flow rate is determined by measuring the average velocity of the flue gas and the cross-sectional area of the duct. The average flue gas velocity is calculated from the average gas velocity pressure ($\Delta P$) across an S-type pitot tube, the average flue gas temperature, the wet molecular weight and the absolute static pressure. The inlet and outlet volumetric flowrates were measured at the beginning and end of each test.

The volumetric flowrate of the inlet air stream was measured in the 8-inch stainless steel inlet duct. The location was nine equivalent diameters downstream of the test mixture vapor breeching and three equivalent diameters upstream of a butterfly valve. The duct had two 3-inch ports 90° apart. A total of 12 traverse points were used, in accordance with EPA Method 1.

The outlet volumetric flowrate was measured in the outlet stack which was 12 inches in diameter. The outlet stack had two 3-inch ports 90° apart. The ports were located approximately 2 equivalent diameters downstream of the top of the catalyst bed and 2 equivalent diameters upstream of the top of the stack. A total of sixteen traverse points were used.

### 5.1.2 UV- Catalytic Oxidizer

A diagram of the sampling system for the UV-catalytic oxidizer is shown in Figure 5-3. Samples to be analyzed for VOC/HAP concentration were collected at the inlet and the outlet of the catalyst bed, and both were analyzed using Method 18.

The volumetric flowrate into the catalyst bed was measured differently for this sytem. A given volume of gas was timed as it passed through a rootsmeter. The temperature and pressure before and after the rootsmeter were measured so that the flowrate could be corrected to standard conditions. The overflow valve shown in Figure 5-3 was used to adjust the flowrate to the catalyst bed.

For this system the humidity of the inlet stream was measured. A psychrometer was placed in the inlet stream, and the wet bulb and dry bulb temperatures were recorded. These temperatures were converted to humidity using a psychrometric chart.

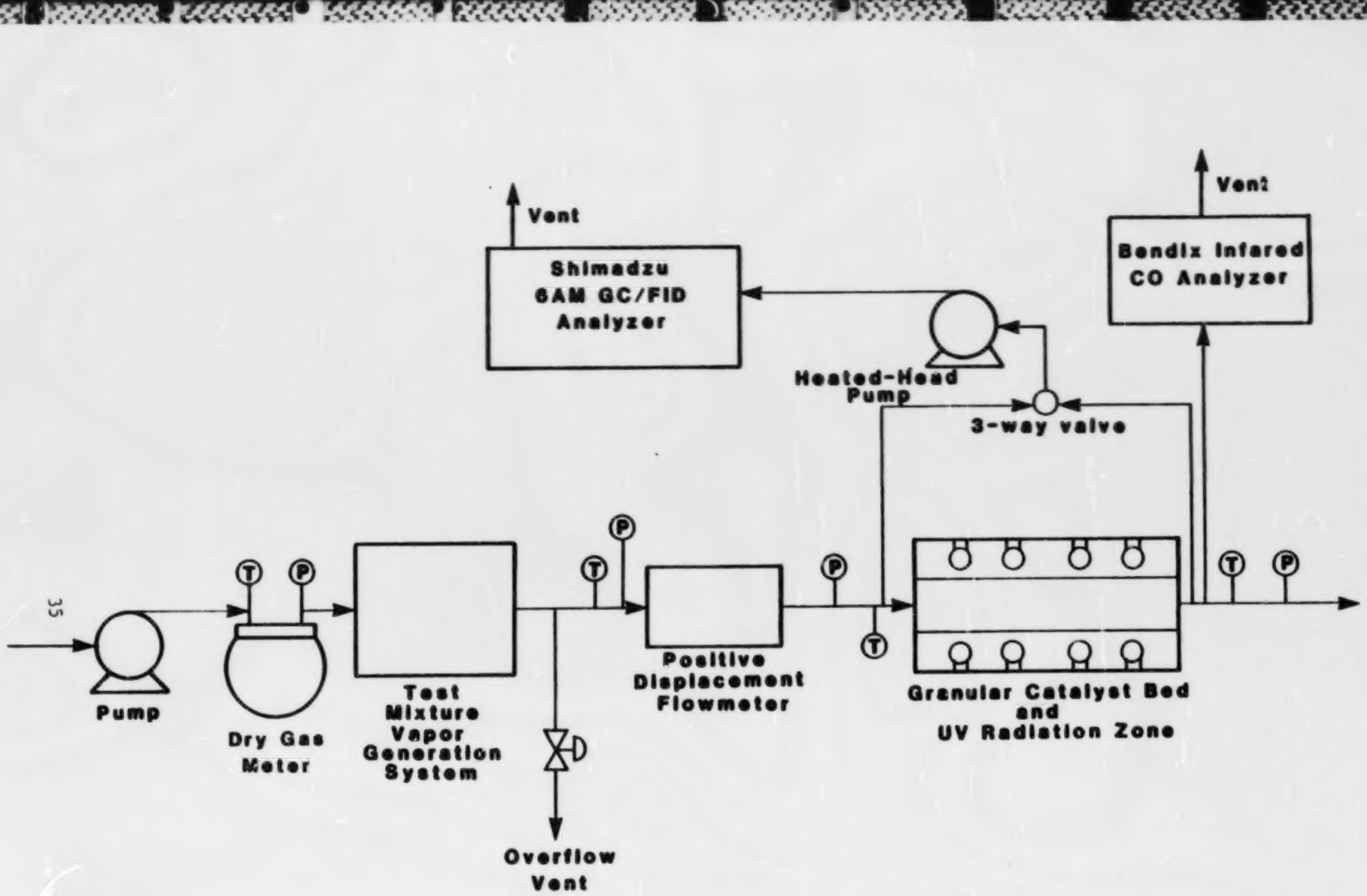
Vent
Shimadzu
6AM GC/FID
Analyzer
Vent
Bendix Infared
CO Analyzer
Heated-Head
Pump
3-way valve
T
P
T
P
P
T
T
P
Pump
Dry Gas
Meter
Test
Mixture
Vapor
Generation
System
Overflow
Vent
Positive
Displacement
Flowmeter
Granular Catalyst Bed
and
UV Radiation Zone

Figure 5-3. Sampling Diagram For UV-Catalytic Oxidizer.

## 5.2 ANALYTICAL METHODS

The analytical methods used in this test program are described in this section. Sections 5.2.1, 5.2.2, 5.2.3, and 5.2.4 contain the analytical methods for the Method 18, tenax-GC sample, GC/MS, and CO analyses, respectively.

### 5.2.1 EPA Method 18

Method 18 provides for individual organic specie quantitation by gas chromotography using a flame ionization detector (GC-FID). This analysis was performed manually for this study using a single instrument. Samples from different locations were analyzed in sucession while test conditions were held constant. The general procedure used was to first analyze three inlet gas samples (i.e. three injections) to verify that the proper liquid injection rates were being used and to characterize the inlet VOC/HAP concentrations. Three outlet gas samples were then analyzed followed by one additional inlet sample, three preheater samples (if applicable), and then one final inlet sample. This approach gave sufficient system inlet data to verify that the liquid injection rate was constant throughout the test run.

A Shimadzu 6AM gas chromatograph with flame ionization detection was utilized for on-line gaseous injections. A 6-port gas sampling valve with a 5 mL stainless steel heated sample loop was used. Gas samples were blown through the sample loop at a constant rate. When the sample loop was thoroughly flushed (at least 100 times the sample loop volume), the gas was introduced onto the chromatographic column. The chromatographic separations were done with a 6 ft. x 1/8 in. stainless steel column packed with 1 percent SP-1000 on 60/80 mesh Carbopack B. Parameters for GC analysis of all mixtures and retention times of each species are presented in Table 5-2.

Each day, the GC/FID was calibrated using compound specific calibration gases which ranged from the mixture inlet concentration down to a concentration of 1 ppmv. Commercially prepared gas standards certified to ±2 percent were used. A Shimadzu Chromatopack integrator/recorder was used to determine and record area counts for each species.

### TABLE 5-2. GC CONDITIONS FOR METHOD 18 ANALYSES

| Text Mixture | Components | Temperature Program | Retention Time |
|---|---|---|---|
| 1 | 1,2-dichloroethylene | 150°C, isothermal | 1.71 |
| | Trichloroethylene | | 4.05 |
| 2 | Pentane | 125°C to 200°C at 15°/min, hold | 2.84 |
| | Cyclohexane | | 3.28 |
| | Trichloroethylene | | 4.14 |
| | Benzene | | 4.39 |
| | Ethylbenzene | | 12.19 |
| 3 | Vinyl chloride | 60°C to 150°C at 20°/min, hold | 1.40 |
| | Trichlorethylene | | 6.65 |
| 4 | 1,2-dichloroethane | 125°C to 200°C at 15°/min, hold | 2.51 |
| | trichloroethylene | | 4.05 |
| | 1,1,2-trichloroethane | | 4.40 |
| | Tetrachloroethylene | | 7.05 |

*Columns for GC analyses and other conditions:

6 ft x 1/8 in SS, 1% SP-1000 on 60/80 mesh on Carbopack B
Carrier: Nitrogen at 30 mL/min
Injector port temp.: 150°C; detector temp.: 270°C
Sample loop for inlet: 5cc

Comparison of test results from the Method 18 and the tenax-GC resin analyses indicate that the detection limit for the Method 18 analysis was 0.03 ppmv for most compounds. This comparatively low detection limit for GC/FID analysis is attributed to a low noise level for the instrument used and the use of a 5 mL sample loop.

### 5.2.2 Analytical Method for GC/FID Analysis of Tenax Resin Samples

The tenax-GC resin samples were analyzed using the analytical method diagrammed in Figure 5-4. First, the tenax tubes were desorbed at 150°C for 10 minutes at a purge rate of 14 mL/min in a desorption oven. The sample was then cryogenically trapped in a stainless steel tube with liquid nitrogen at -150°C. Finally, the sample was flash vaporized onto the GC column of a Varian 3400 gas chromatograph with a flame ionization detector. The Varian 3400 GC/FID had dual packed columns and dual FID's.

Parameters for GC analysis of all mixtures and retention times for each species are summarized in Table 5-3. A Varian Vista 402 data system and dual channel printer/plotter was used to determine and record area counts for each species.

Calibration of the GC/FID was performed with tenax-GC traps that were loaded with know amounts of the test mixture compounds. These traps were loaded by passing commercially prepared calibration gases (±2 percent) through the traps at known flowrates for a timed period. The flowrate through the trap was measured using a bubble flowmeter. The mass of each species loaded onto the trap was calculated from the flowrate, time and concentration in the gas standard.

The tenax-GC resin traps were blanked before use by baking them at 180°C for 12 to 24 hours while purging with nitrogen. Each day a set of traps was analyzed on the Varian GC/FID as analytical blanks. The estimated detection limit for the tenax-GC sampling/analysis method is 1 to 5 ppbv for a 1L flue gas sample drawn through the tenax-GC trap.

A breakthrough study was performed prior to testing to verify that a backup tenax-GC resin trap would not be needed for the sampling to be performed. Two blank tenax tubes were loaded in series with known amounts

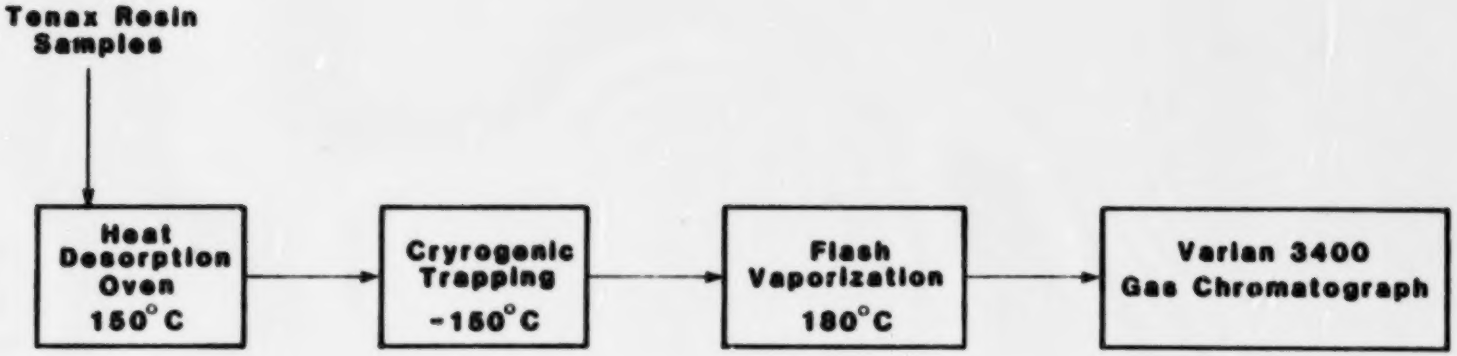
Tenax Resin Samples
Heat Desorption Oven 150°C
Cryrogenic Trapping -150°C
Flash Vaporization 180°C
Varian 3400 Gas Chromatograph

Figure 5-4. Flow Diagram For Tenax-GC Resin Sample Analysis.

TABLE 5-3. GC CONDITIONS FOR VARIAN 3400

| Text Mixture | Compound | Temperature Program[b] | Retention Time |
|---|---|---|---|
| 1 | Dichloroethylene | 40°C, hold 5 min, then 40°C/min | 8.0 |
| | Trichloroethylene | to 200°C, hold 5 min. | 9.3 |
| 2 | Pentane | Same as Mixture 1 | 8.6 |
| | Cyclohexane | | 9.0 |
| | Trichloroethylene | | 9.5 |
| | Benzene | | 9.6 |
| | Ethylbenzene | | 15.9 |
| 4 | 1,2-dichloroethane | Same as Mixture 1 | 8.5 |
| | trichloroethylene | | 9.5 |
| | 1,1,2-trichloroethane | | 9.7 |
| | Tetrachloroethylene | | 11.6 |

[a] Tenax-GC traps were not analyzed by GC/FID for Mixture 3.

[b] Other Conditions:

Injector port temperature: 160°C
Detector temperature: 250°C
Desorption heater: 150°C
Cryogenic trap: -150°C
Transfer line temperature: 130°C
Purge: 14 mL/min for 10 minutes
Carrier gas: nitrogen

of trichloroethylene and dichloroethylene from a calibration standard. The second tube in the series was then analyzed for breakthrough on the Varian 3400 GC/FID. Two sets of traps were loaded with 15,000 to 20,000 ng of each compound and four sets of traps were loaded with 25,000 to 34,000 ng. These loadings were much higher than the typical loadings of 1,000 to 3,000 ng observed for the actual samples.

The results of the breakthrough study are summarized in Table 5-4. As shown in Table 5-4, an average of 98.6 percent of the dichloroethylene and 99.7 percent of the trichloroethylene were retained on the first trap. Based on the data presented in Table 5-4 backup tenax-GC traps were considered unnecessary for this test program.

### 5.2.3 GC/MS Analytical Procedure

Tenax-GC resin samples provided by Radian were analyzed by the Headquarters Air Force Engineering and Services Center at Tyndall AFB to identify products of incomplete oxidation. The tenax-GC traps were purged onto a standard purge and trap device (Tekmar LSC-2) by flowing 40 mL/min of nitrogen through the traps for 20 minutes at 180°C. The sample was then desorbed from the Tekmar into a Hewlett Packard 5987A gas chromatograph/mass spectrometer (GC/MS). The separations were done with a 9' x 1/8" stainless steel column packed with 1 percent SP-1000 on 60/80 mesh Carbopack B. The GC temperature was held initially for 3 minutes at 50°C and then increased to 220°C at 8°C/min. Helium was used as the carrier gas at a flowrate of 35 mL/min.

Compounds found in the samples were quantitated against a tenax-GC trap with known quantities of 1,2-dichloroethane, 1,1,1-trichloroethane, trichloroethylene and tetrachloroethylene (Mixture 4). The trap used for quantitation was loaded by Radian using the commercially prepared standard available for Method 18 calibrations.

### 5.2.4 Carbon Monoxide Analysis

Carbon monoxide concentration was determined with a Bendix Model 8501 Infrared Gas Analyzer (IR). The IR analyzer contained an internal pump and

TABLE 5-4. RESULTS OF BREAKTHROUGH STUDY

| Trial | Dichloroethylene | | Trichloroethylene | |
|---|---|---|---|---|
| | Total Mass Loaded (ng) | Mass Retained on 1st Trap (%) | Total Mass Loaded (ng) | Mass Retained on 1st Trap (%) |
| 1 | 15466 | 99.9 | 19354 | 98.7 |
| 2 | 15981 | 99.9 | 19999 | 99.8 |
| 3 | 26904 | 94.7 | 33667 | 99.7 |
| 4 | 26904 | 97.8 | 33667 | 99.9 |
| 5 | 25991 | 99.7 | 32525 | 99.9 |
| 6 | 26582 | 99.3 | 33264 | 99.9 |
| Avg. | | 98.6 | | 99.7 |

flow controls for proper flow through the sample cell. The internal pump was used to withdraw a gas sample from the incinerator or oxidizer outlet stack for analysis. The IR analyzer has the capability to measure carbon monoxide concentrations up to 1,000 ppm. The CO monitor was calibrated daily at 0, 10, and 50 ppm.

## 6.0 STATISTICAL METHODS

Statistical analyses were performed on results from this study to: (1) assess the analytical variability in the destruction efficiencies measured at each test condition, and (2) test the hypothesis that observed differences in destruction efficiencies were due to parametric effects instead of random or analytical error.

Prior to conducting the statistical analyses, the raw analytical and process data were entered into a data base for manipulation on the SAS system[2]. SAS is a computer system designed for statistical analysis, which provides information storage and retrieval, data modification and programming, report writing, and file handling. Evaluation and interpretation of the pilot unit test results were performed using SAS general linear models routines.

The analysis of covariance (ANCOVA) technique was used to test the hypothesis that test parameters significantly influence destruction efficiency. A detailed discussion of this analysis technique is contained in Reference 3 (Brownlee, K. A.). The technique allows the effect of a single variable on destruction efficiency to be analyzed even though other parameters may also vary for the test runs being compared. For example, an accurate comparison of destruction efficiencies for two catalyst inlet temperatures may be difficult if inlet concentration and space velocity were not the same for two test runs. However, through use of the ANCOVA technique, the average destruction efficiencies can be "adjusted" to approximate the destruction that would have been obtained if both measurements had been made at the same inlet concentration and space velocity. In making the adjustments to the measured destruction efficiencies, the relationship between the covariates of inlet concentration and space velocity and the dependent variable, destruction efficiency, was assumed to be linear. Scatter plots of the data indicate that this assumption is reasonable over the range of conditions tested. In order to determine whether measureable, or statistically significant, differences exist among the adjusted average destruction efficiencies, the ANCOVA separates the total variation that is present in the data into exclusive components and then tests hypotheses about those components. Statistical significance was tested at both the 90 percent confidence level (indicating a marginal effect) and the 95 percent confidence level.

Results from the ANCOVA also provided an estimate of between-day variability that was used with the student's distribution to estimate the 95 percent confidence intervals for compound specific and total mixture destruction efficiencies. The between-day variability was found to be substantially lower for efficiencies at or above 95 percent compared to those below 95 percent. The standard deviation for system and catalyst destruction efficiencies greater than or equal to 95 percent was 0.44. Below 95 percent, standard deviations were 1.80, 3.19 and 6.81 for system, catalyst, and heater destruction efficiencies respectively.

# 7.0 FLUIDIZED-BED INCINERATOR RESULTS

The fluidized-bed catalytic incinerator testing characterized performance of the incinerator over a range of catalyst inlet temperatures and investigated effects of other parameters, such as inlet VOC concentration, space velocity, and mixture composition. The testing also provided information on: (1) the effect of air-to-gas (fuel) ratio, (2) potential products of incomplete oxidation, and (3) carbon monoxide emissions.

All four of the test mixtures showed destruction efficiencies in the 97 to 99 percent range at sufficiently high catalyst inlet temperatures. Mixture composition, air-to-gas ratio, and space velocity showed minimal effects on destruction efficiency; inlet VOC concentration showed no effect. Several chlorinated products of incomplete oxidation were identified and stack gas carbon monoxide concentrations averaged below 100 parts per million by volume (ppmv).

The results discussion presented in this section is divided into seven parts:

7.1 Temperature and Space Velocity Effects
7.2 Mixture Effects
7.3 Relative Compound Destruction
7.4 Effect of Inlet Concentration
7.5 Products of Incomplete Oxidation
7.6 Potential HCl Emissions
7.7 Comparison of Method 18 and Tenax-GC Methods

Destruction efficiencies are based inlet and outlet VOC mass flowrates. Inlet and outlet concentrations were determined by Method 18 and gas flowrates were measured by Method 2. At some conditions outlet concentrations were also determined using a tenax-GC resin sampling/analysis method. Inlet and outlet VOC samples were quantitated using commercially prepared compound specific standards. Method 18 destruction efficiencies showing a "greater than" (>) sign indicate that one or more of the mixture components in the outlet sample were below the detection limit. The detection limit for Method 18 was 0.03 ppmv for most species. This low detection limit for Method 18, which is attributed to a low detector noise level and a 5 mL sample loop, is based on a comparison of the Method 18 and tenax-GC sampling/analysis results. Total hydrocarbon or "mixture" destruction efficiencies were determined using the sum of mixture component concentrations in the inlet and outlet gas streams.

Confidence intervals presented in this section are based on variability estimates made using destruction efficiencies measured at all test conditions. For each condition, a minimum of three samples were analyzed for each VOC sampling location. The variability in destruction efficiency was found to be substantially lower for efficiencies at or above 95 percent compared to efficiencies below 95 percent.

## 7.1 EFFECTS OF INLET TEMPERATURE AND SPACE VELOCITY

The effects of catalyst inlet temperature and space velocity on the destruction efficiency of the fluidized-bed incinerator are discussed in this section. The mixtures tested during this study were discussed in Section 4.0, and are listed again in Table 7-1 for reference. The effect of temperature and space velocity on mixture destruction efficiencies are discussed in Section 7.1.1 and the effects on component destruction are discussed in Section 7.1.2. Data on system, catalyst, and heater destruction are presented.

### 7.1.1 Effects on Mixture Destruction

System, catalyst, and heater destruction efficiencies for Mixtures 1 through 4 are shown in Table 7-2 for two space velocities and for temperatures ranging from 650 to 950°F. The average efficiencies presented in Table 7-2 show the expected trends of increased system and catalyst destruction efficiency with increasing temperature and decreasing space velocity. Statistical analysis indicates that the observed trend for

TABLE 7-1. MIXTURE COMPOSITIONS FOR CATALYTIC OXIDATION TESTS

| Mixture Designation | Mixture Compounds |
|---|---|
| Mixture 1 | Trichloroethylene<br>1,2 dichloroethylene |
| Mixture 2 | Trichloroethylene<br>Benzene<br>Ethylbenzene<br>Pentane<br>Cyclohexane |
| Mixture 3 | Vinyl Chloride<br>Trichloroethylene |
| Mixture 4 | 1,2 dichloroethane<br>Trichloroethylene<br>1,1,2-trichloroethane<br>Tetrachloroethylene |

## TABLE 7-2. SUMMARY OF SYSTEM PARAMETERS AND SYSTEM, CATALYST AND HEATER DESTRUCTION EFFICIENCIES FOR THE FLUIDIZED-BED CATALYTIC INCINERATOR TEST SYSTEM

| Run Number | Test Mixture | System Inlet Concentration (ppmv) | Space Velocity ($hr^{-1}$) | Catalyst Temperatures | | Destruction Efficiencies, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | System | | Catalyst | | Heater | |
| | | | | Inlet (°F) | Outlet (°F) | Mean | 95% Confidence Interval | Mean | 95% Confidence Interval | Mean | 95% Confidence Interval |
| B-3 | 1 | 13.1 | 10,300 | 648 | 633 | 86 | 83.4 - 87.8 | 78 | 70.5 - 86.3 | 33 | 16.3 - 50.1 |
| B-1 | 1 | 12.8 | 10,300 | 701 | 683 | 88 | 83.1 - 92.1 | 82 | 73.9 - 89.7 | 32 | 15.2 - 49.0 |
| B-4[a] | 1 | 16.7 | 10,100 | 792 | 768 | 93 | 90.4 - 94.8 | 87 | 79.0 - 94.8 | 44 | 35.1 - 52.1 |
| B-15[a] | 1 | 17.8 | 9,960 | 801 | 778 | 92 | 90.2 - 93.6 | 86 | 78.5 - 94.3 | 41 | 34.6 - 47.2 |
| B-29[a] | 1 | 17.7 | 10,700 | 801 | 780 | 95 | 92.0 - 97.9 | 92 | 87.7 - 95.7 | 39 | 30.2 - 47.2 |
| B-7[b] | 1 | 17.3 | 9,810 | 943 | 915 | 98 | 97.1 - 98.3 | 95 (97) | 94.0 - 96.2 | 53 | 45.0 - 62.0 |
| B-2[b] | 1 | 17.7 | 6,800 | 709 | 687 | 91 (92) | 89.1 - 92.1 | 89 (90) | 84.0 - 94.2 | 14 | 7.2 - 19.8 |
| B-5 | 1 | 19.2 | 6,840 | 794 | 764 | 95 | 92.6 - 97.0 | 93 | 84.9 - 100 | 28 | 10.7 - 44.5 |
| B-6[b] | 1 | 17.8 | 6,720 | 943 | 901 | 98 (99) | 97.4 - 98.0 | 95 (98) | 87.0 - 100 | 55 | 49.4 - 59.8 |
| B-10[b] | 2 | 39.1 | 10,800 | 654 | 643 | 93 (93) | 91.2 - 95.6 | 89 (89) | 81.2 - 97.0 | 39 | 28.2 - 49.8 |
| B-8[a] | 2 | 40.8 | 10,500 | 807 | 788 | 98 | 97.7 - 99.1 | 96 | 95.4 - 97.6 | 56 | 44.9 - 66.5 |
| B-14[a,b] | 2 | 42.8 | 10,400 | 801 | 784 | 98 (99) | 96.0 - 100 | 97 (98) | 95.7 - 97.9 | 45 | 33.8 - 55.4 |
| B-13[b] | 2 | 42.9 | 9,730 | 932 | 906 | 99+(99+) | 98.5 - 99.7 | >98 (98) | - | 59 | 48.0 - 69.6 |
| B-9[b] | 2 | 33.3 | 7,790 | 653 | 640 | 96 (95) | 95.4 - 96.4 | 93 (91) | 84.6 - 100 | 46 | 35.0 - 56.6 |
| B-11[b] | 2 | 37.8 | 6,820 | 803 | 774 | 98 (99) | 98.3 - 99.4 | - | - | - | - |
| B-12[b] | 2 | 42.1 | 6,290 | 947 | 913 | 99+(99+) | 99.0 - 100 | >98 (99+) | - | 63 | 45.8 - 79.6 |
| B-26 | 3 | 12.4 | 11,300 | 648 | 629 | 89 | 86.4 - 92.2 | 85 | 80.2 - 90.4 | 27 | 16.5 - 38.1 |
| B-28 | 3 | 9.92 | 10,500 | 947 | 919 | 98 | 97.6 - 99.0 | 97 | 95.4 - 97.6 | 53 | 42.3 - 63.9 |
| B-25 | 3 | 10.7 | 7,350 | 656 | 637 | 92 | 89.2 - 95.0 | 91 | 82.8 - 98.6 | 15 | 4.4 - 26.0 |
| B-27 | 3 | 10.5 | 6,970 | 798 | 765 | 97 | 95.9 - 97.3 | - | - | - | - |
| B-24 | 3 | 8.71 | 6,530 | 952 | 911 | >97 | - | >94 | - | 56 | 47.0 - 64.0 |
| B-17 | 4 | 50.2 | 10,600 | 653 | 635 | 72 | 68.8 - 74.6 | 64 | 56.6 - 72.4 | 20 | 9.5 - 31.1 |
| B-19 | 4 | 57.1 | 10,200 | 953 | 926 | 96 (97) | 95.6 - 97.0 | 93 (94) | 85.2 - 100 | 45 | 28.3 - 62.1 |
| B-16[a] | 4 | 42.2 | 7,430 | 649 | 632 | 75 | 60.0 - 75.8 | 68 | 72.1 - 77.9 | 22 | 5.3 - 39.1 |
| B-20 | 4 | 43.6 | 7,770 | 654 | 636 | 76 | 73.7 - 78.1 | 71 | 63.5 - 79.3 | 16 | 5.0 - 26.6 |
| B-18[b] | 4 | 46.5 | 6,530 | 952 | 917 | 97 (98) | 95.9 - 97.3 | 93 (97) | 84.6 - 100 | 54 | 37.3 - 71.1 |
| B-22 | 4 | 192 | 11,200 | 660 | 645 | 72 | 69.9 - 74.3 | 65 | 60.2 - 70.4 | 20 | 8.9 - 30.5 |
| B-23 | 4 | 216 | 10,200 | 953 | 931 | 95 | 94.8 - 95.8 | 93 | 87.6 - 97.8 | 36 | 28.9 - 43.3 |

[a] These test runs are replicates.

[b] Destruction efficiencies for these test runs were determined by Method 18 and the GC-Tenax resin sampling method. The mean destruction efficiencies determined by Method 18 are presented with the GC-Tenax result in parenthesis. The confidence interval shown is for the Method 18 result. The Tenax-GC resin confidence intervals are contained in Appendix C.

catalyst inlet temperature is statistically significant at the 95 percent confidence level. However, the trend observed for space velocity was not found to be statistically significant for the narrow range of space velocities tested. As discussed in Section 3.0, the range of space velocities that could be tested for the fluidized-bed system was limited by: (1) the inlet blower size and (2) the need to maintain catalyst fluidization.

System destruction efficiencies for the four mixtures are shown as a function of temperature in Figures 7-1 and 7-2. Data in Figures 7-1 and 7-2 were collected at the high (10,500 $hr^{-1}$) and low (7,000 $hr^{-1}$) space velocities, respectively.

As shown in Figures 7-1 and 7-2, the highest destruction efficiencies were observed for Mixture 2 and the lowest efficiencies were observed for Mixture 4. The effect of temperature on destruction also seems to be much stronger for Mixture 4 than the other three mixtures. The observed order of increasing ease of destructability, Mixture $4<1<3<2$, was verified for any given temperature by statistical analysis results. Identical trends in the effect of temperature on each mixture and the order of destructability were also found for catalyst destruction efficiencies. Data for catalyst destruction at the high space velocity are presented in Figure 7-3 for comparison.

Heater destruction efficiencies for the four mixtures are shown for both space velocities in Figure 7-4. As shown in Figure 7-4, the heater destruction efficiencies generally ranged from about 20 to 50 percent, and thus contributed substantially to the overall system destruction efficiency at most test conditions. This finding suggests that catalytic incinerator performance may be improved by preheater designs that optimize contacting between the inlet gas stream and the flame zone. The effect that this improved preheater destruction may have on the formation of products of incomplete oxidation, if any, is not known.

At low space velocities, the data in Figure 7-4 show that heater destruction for Mixture 2 was significantly higher than that for Mixtures 1, 3, and 4. Also, a much weaker influence of temperature on heater destruction is seen for Mixture 2 compared to the other three mixtures.

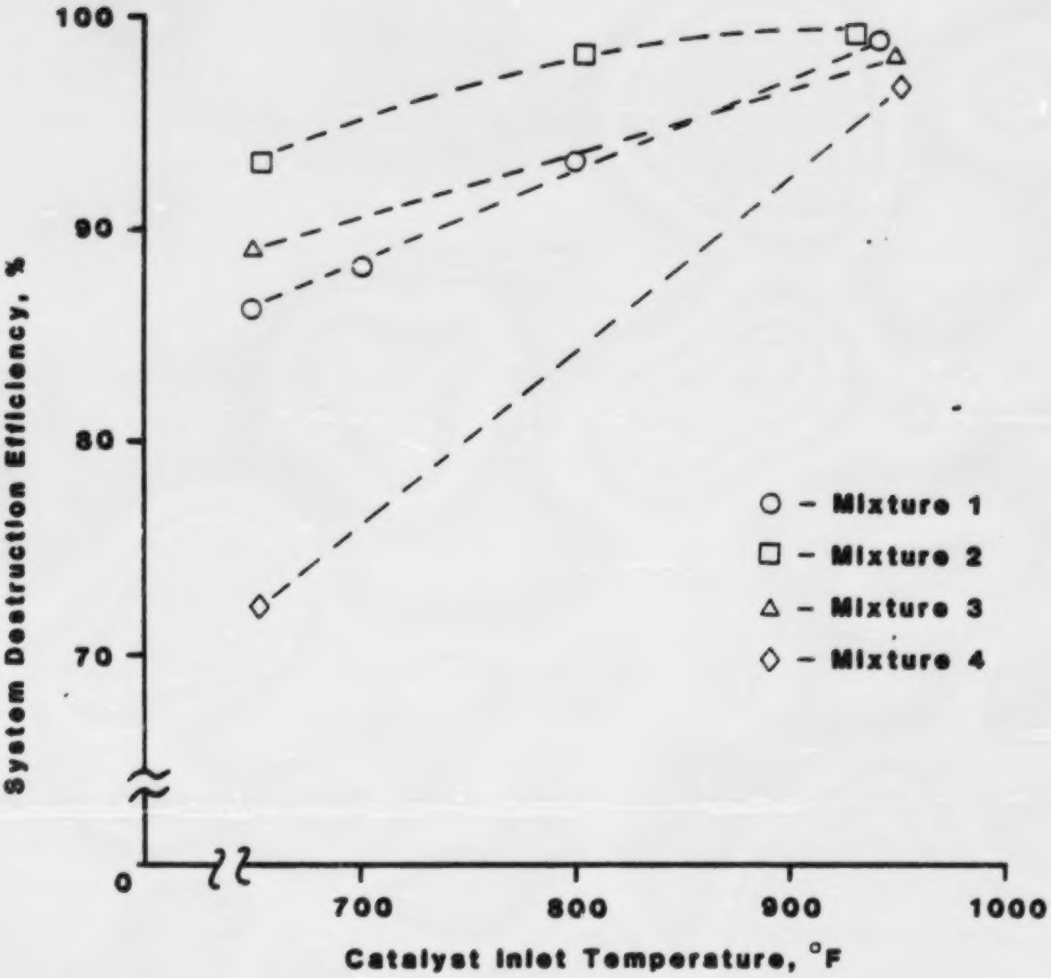

Figure 7-1. System Destruction Efficiencies As A Function Of Catalyst Inlet Temperature For All Mixtures At A Space Velocity of 10,500 $hr^{-1}$.

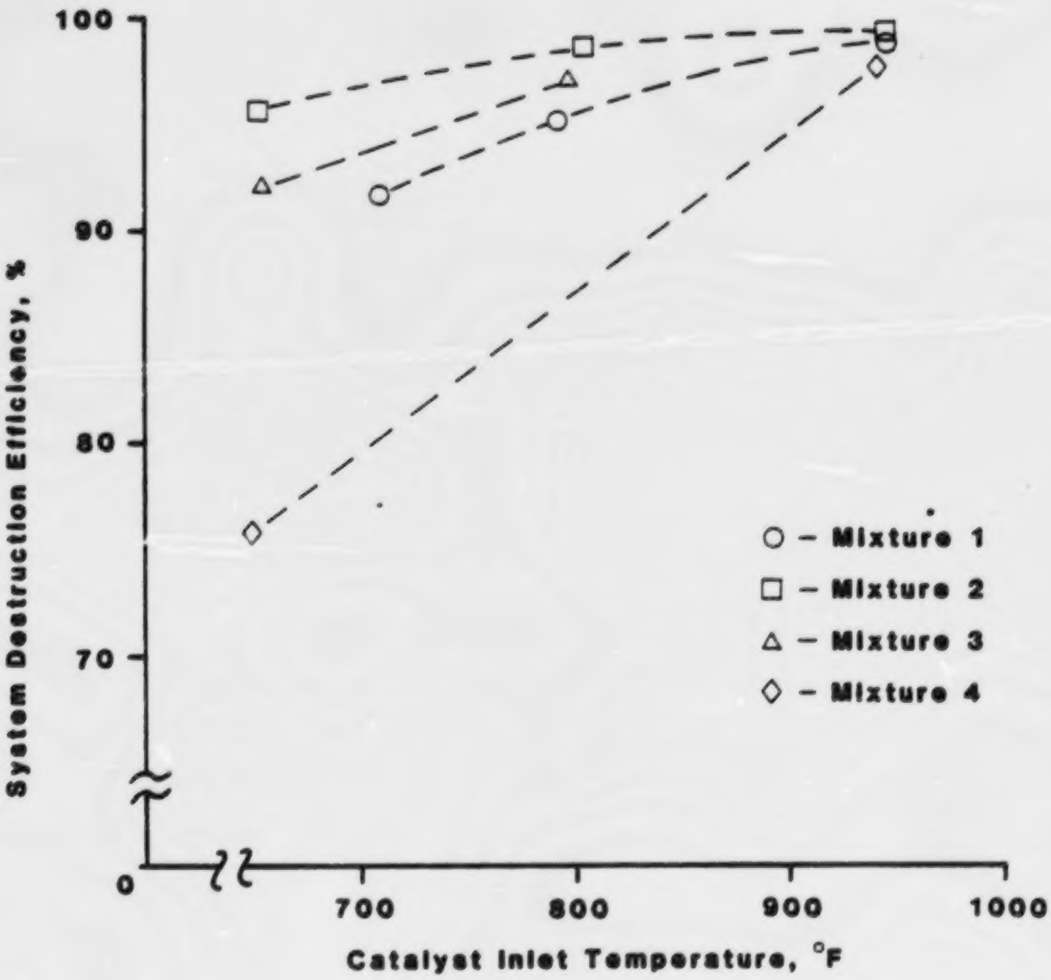

Figure 7-2. System Destruction Efficiencies As A Function Of Catalyst Inlet Temperature For All Mixtures At A Space Velocity of 7,000 $hr^{-1}$.

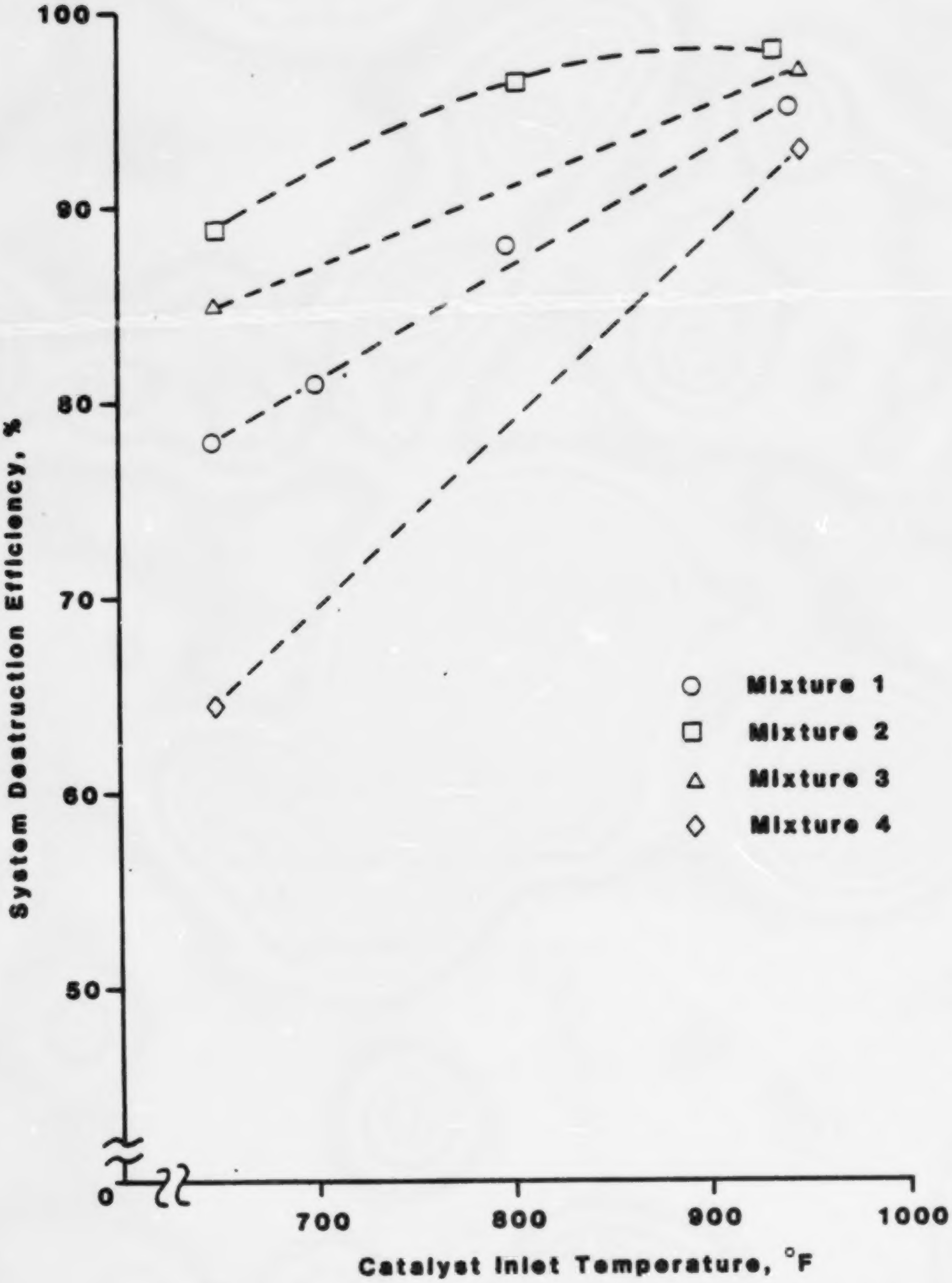

Figure 7-3. Catalyst Destruction Efficiencies As A Function of Catalyst Inlet Temperature For All Four Mixtures At A Space Velocity of 10,500 $hr^{-1}$.

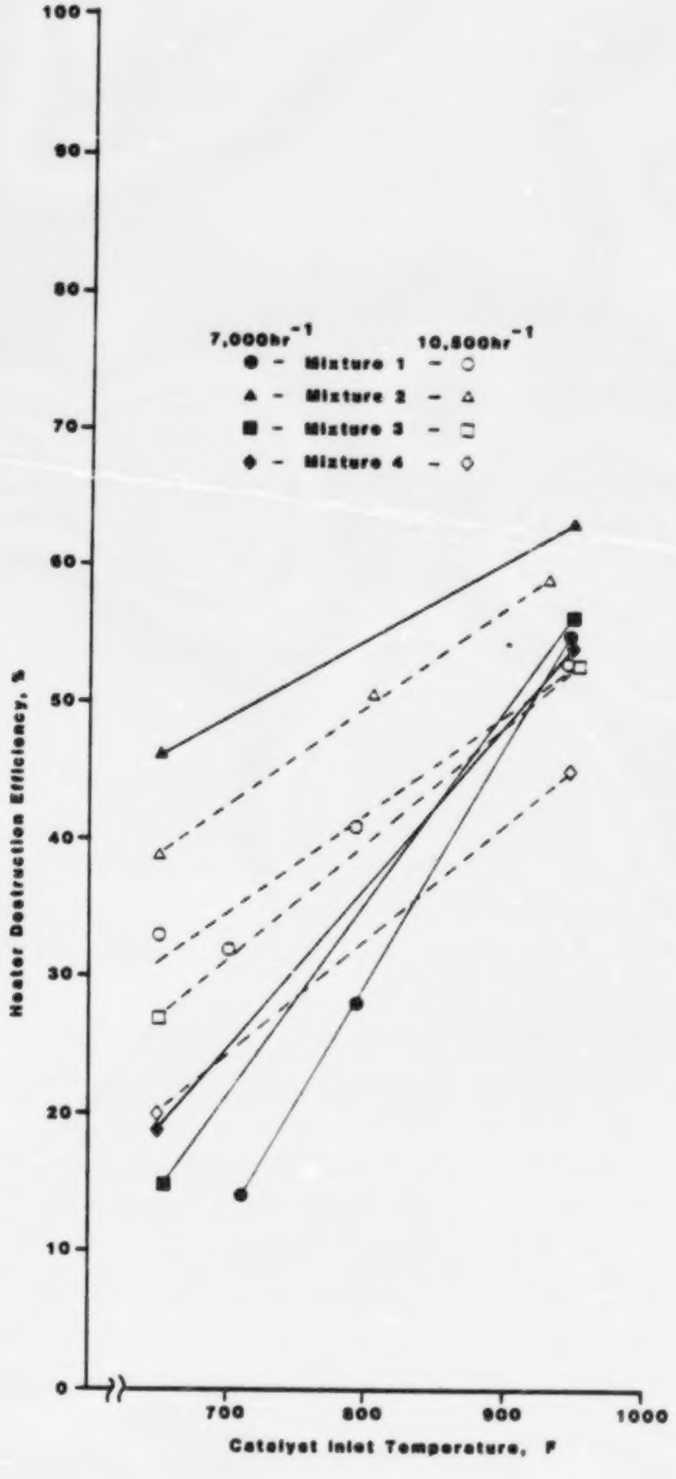

Figure 7-4. Heater Destruction Efficiencies As A Function of Temperature For All Mixtures At Two Space Velocities.

At the high space velocity, the data in Figure 7-4 show similar trends of increasing heater destruction with increasing catalyst inlet temperature for all four mixtures. Heater destruction is highest for Mixture 2 and lowest for Mixture 4, as was observed for the system and catalyst destruction efficiencies presented in Figures 7-1 through 7-3.

### 7.1.2 Effects on Component Destruction

The effects of catalyst inlet temperature on component destruction efficiencies are discussed in this section. This discussion is based primarily on a graphical presentation of system destruction efficiency data for the higher space velocity of (10,500 $hr^{-1}$). Trends in system destruction at the lower space velocity (7,000 $hr^{-1}$) and trends in catalyst destruction at both space velocities were all found to be similar to those noted in this section. A complete listing of component specific destruction efficiencies is presented in Appendix C, along with Method 18 and tenax-GC mixture destruction efficiencies.

Results from a quality assurance audit performed during testing with Mixture 2 showed unacceptably high errors in benzene concentrations measured by Method 18 at levels below about 0.2 ppmv. Due to this finding, all destruction efficiencies presented for benzene in this section are based solely on outlet concentrations determined by the tenax-GC method. Quality assurance and quality control data for this program are discussed in Appendix A.

System destruction efficiencies for Mixture 1 components at a space velocity of 10,500 $hr^{-1}$ are presented in Figure 7-5. As shown in Figure 7-6, both dichloroethylene and trichloroethylene showed similar destruction efficiencies and similar trends of increasing destruction with increasing catalyst inlet temperature. The trends with temperature were found to be statistically significant for both compounds.

System destruction efficiencies for Mixture 3 components are presented in Figure 7-6. Data in Figure 7-6 show a higher destruction efficiency for vinyl chloride compared to trichloroethylene at the low temperature. A somewhat weaker (but significant) trend of increasing destruction with temperature is also seen for vinyl chloride compared to trichloroethylene.

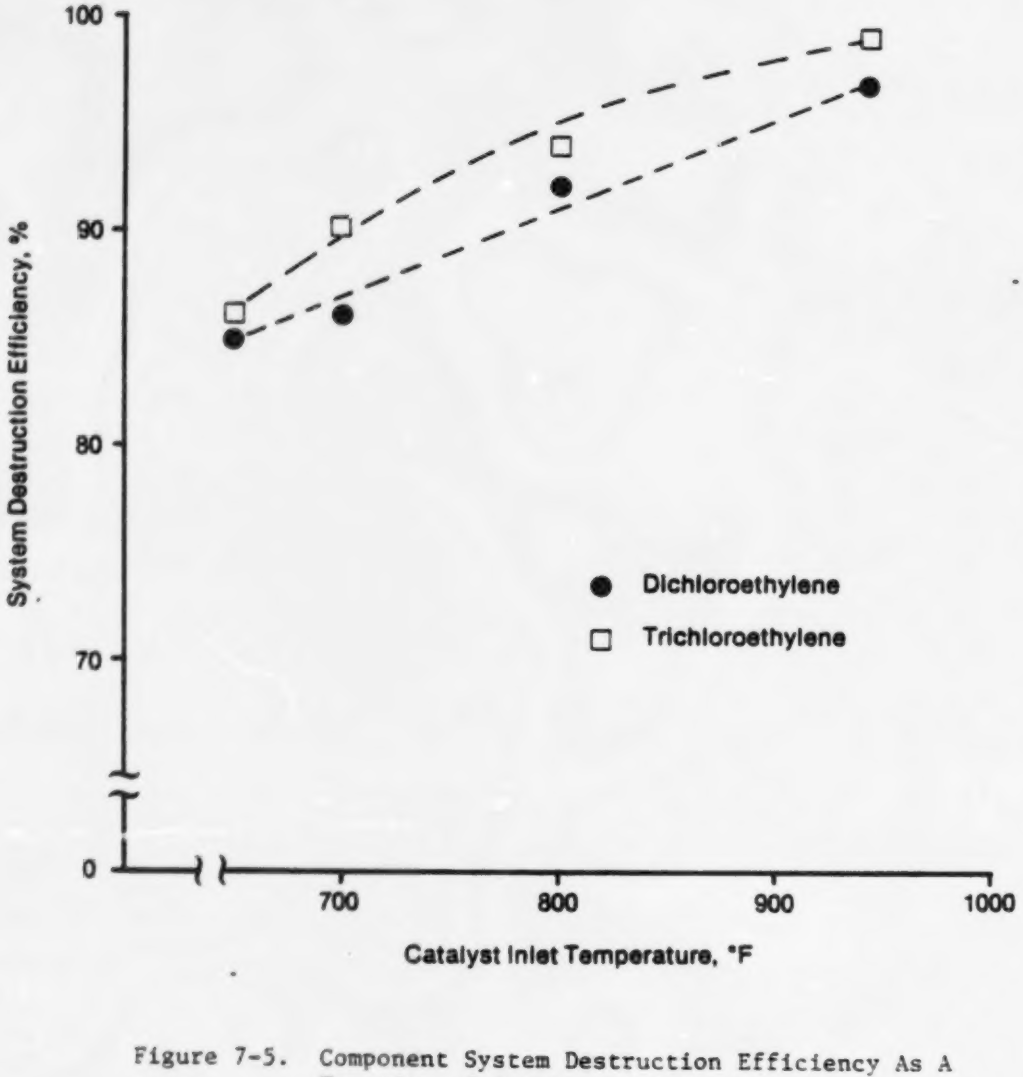

Figure 7-5. Component System Destruction Efficiency As A Function of Catalyst Inlet Temperature For Mixture 1 At A Space Velocity Of 10,500 $hr^{-1}$.

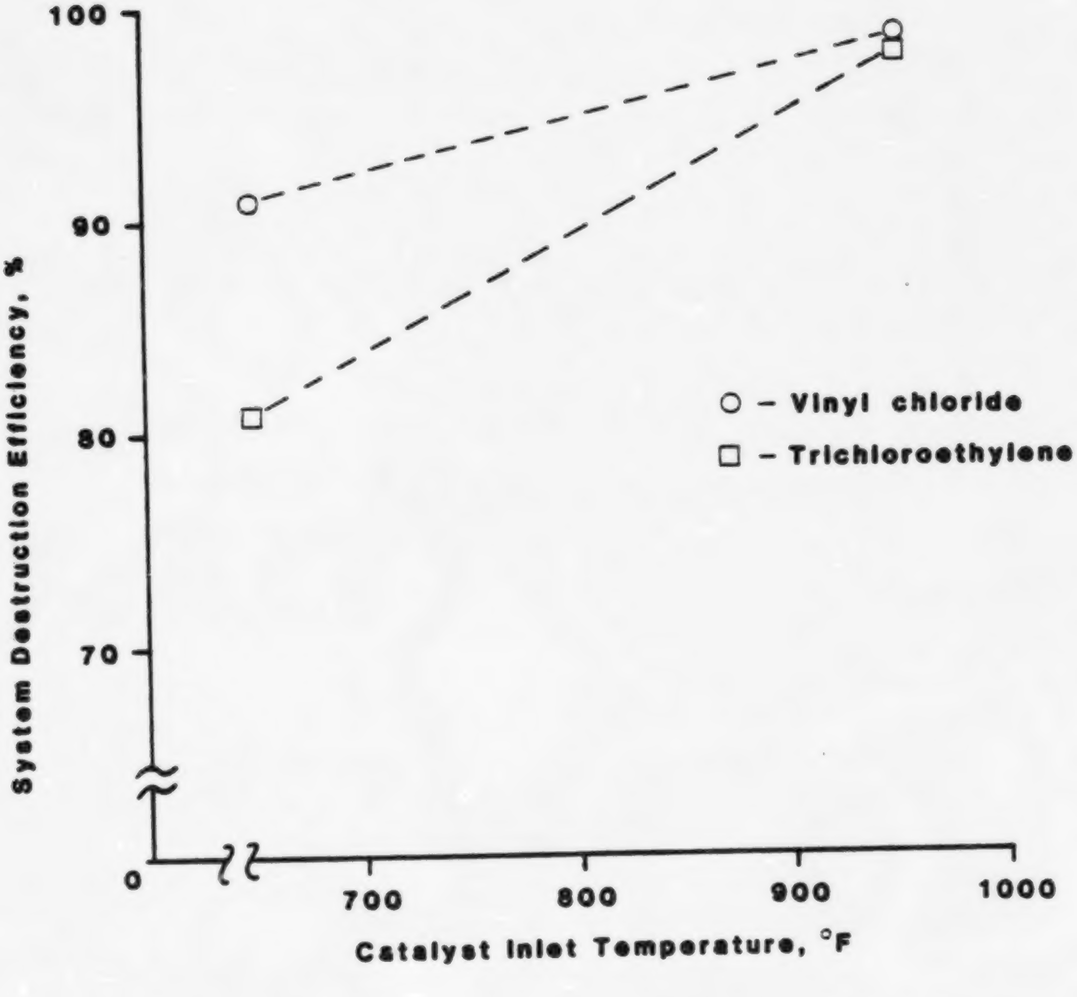

Figure 7-6. Component System Destruction Efficiency As A Function of Catalyst Inlet Temperature For Mixture 3 At A Space Velocity of 10,000 $hr^{-1}$.

Data for Mixture 4 components at the high space velocity are presented in Figure 7-7. As shown in Figure 7-7, destruction efficiencies for tetrachloroethylene are substantially lower than those for the other three compounds in this mixture. The presence of tetrachloroethylene in this mixture appears to be the primary reason that Mixture 4 overall destruction efficiencies for Mixture 4 were below those for Mixtures 1, 2, and 3.

System destruction efficiencies for Mixture 2 components at the high and low space velocities are shown in Figures 7-8 and 7-9, respectively. Comparison of the data for the two space velocities shows similar trends for each of the five components, although destruction efficiencies are slightly higher for the lower space velocity (Figure 7-9).

The data in Figures 7-8 and 7-9 show much lower destruction efficiencies for trichloroethylene and benzene compared to pentane, cyclohexane, and ethyl benzene at 650°F. At higher temperatures, destruction efficiencies for both trichloroethylene and benzene increase dramatically. Inlet temperature was not found to have a statistically significant effect on pentane and ethylbenzene destruction efficiencies and only a marginally significant effect (90 percent confidence level) was found for cyclohexane.

The dramatic increase in the trichloroethylene and, in particular, the benzene destruction efficiency with temperature in Mixture 2 may somehow be related to component inlet concentration. Measured inlet concentrations for benzene were 2 ppmv, inlet concentrations for trichloroethylene were 3 ppmv (in Mixture 2), and inlet concentrations for ethylbenzene, pentane and cyclohexane were 8, 12, and 15 ppmv, respectively. Insufficient data are available to assess whether the dramatic destruction efficiency increase is due to (1) a diffusion effect caused by the low concentration, (2) a much slower reaction rate for benzene on the catalyst surface at low temperature, or (3) catalyst selectivity for compounds other than benzene.

## 7.2 MIXTURE EFFECTS

Effects of mixture composition on the destruction efficiency of trichloroethylene were evaluated by comparing the efficiencies observed for

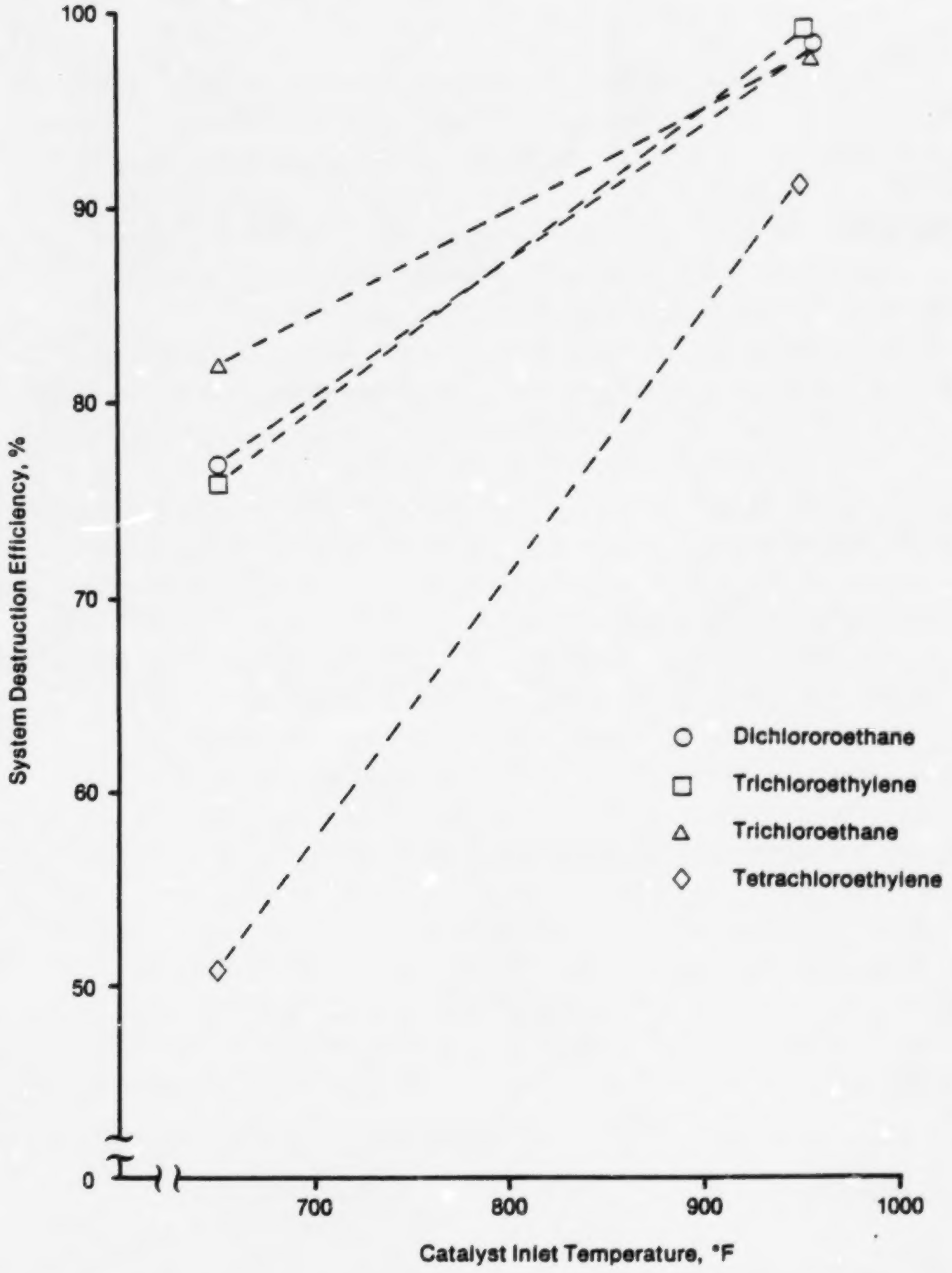

Figure 7-7. Component System Destruction Efficiency As A Function of Catalyst Inlet Temperature For Mixture 4 At A Space Velocity of 10,500 $hr^{-1}$.

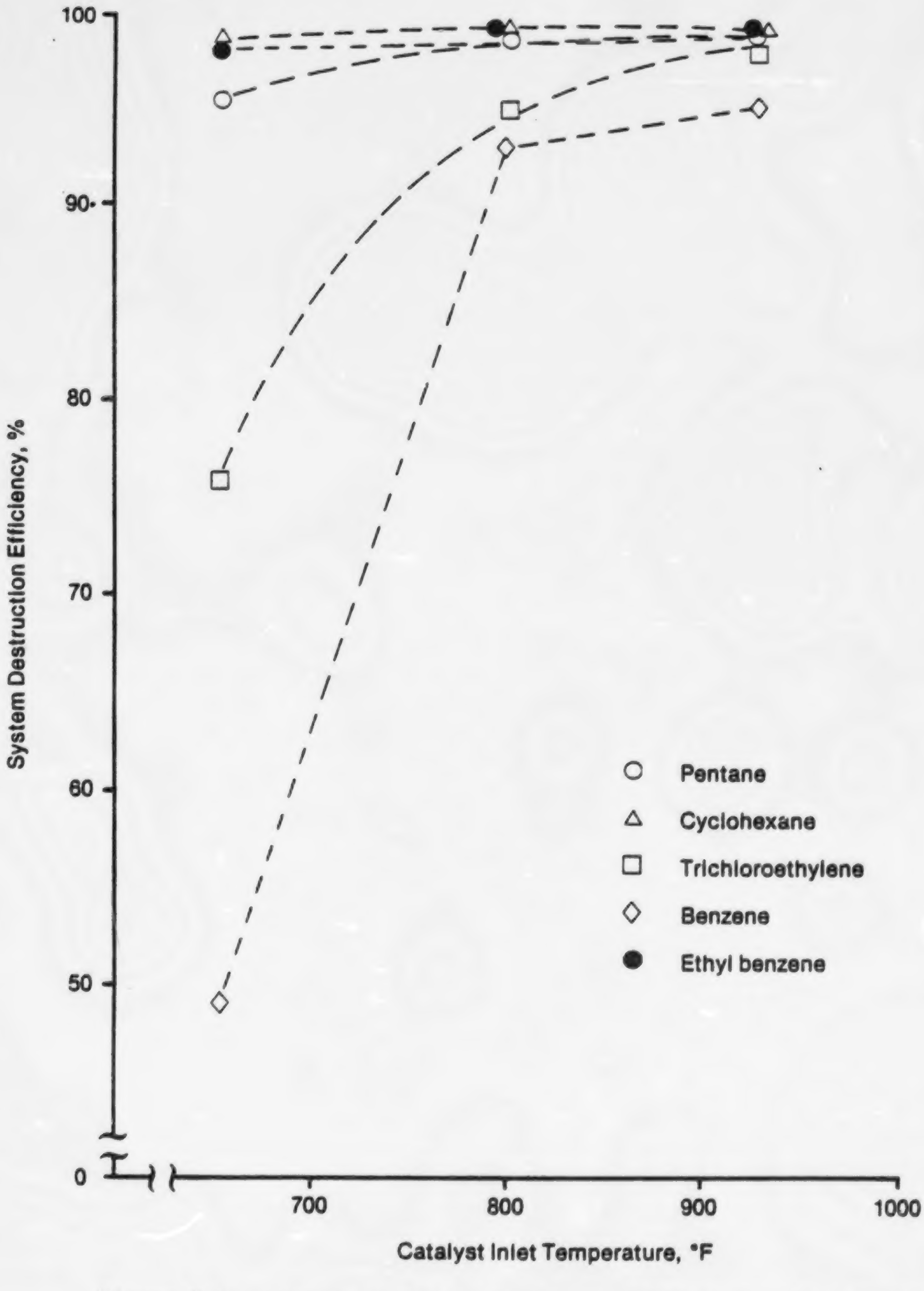

Figure 7-8. Component System Destruction Efficiency As A Function of Catalyst Inlet Temperature For Mixture 2 At A Space Velocity of 10,500 $hr^{-1}$.

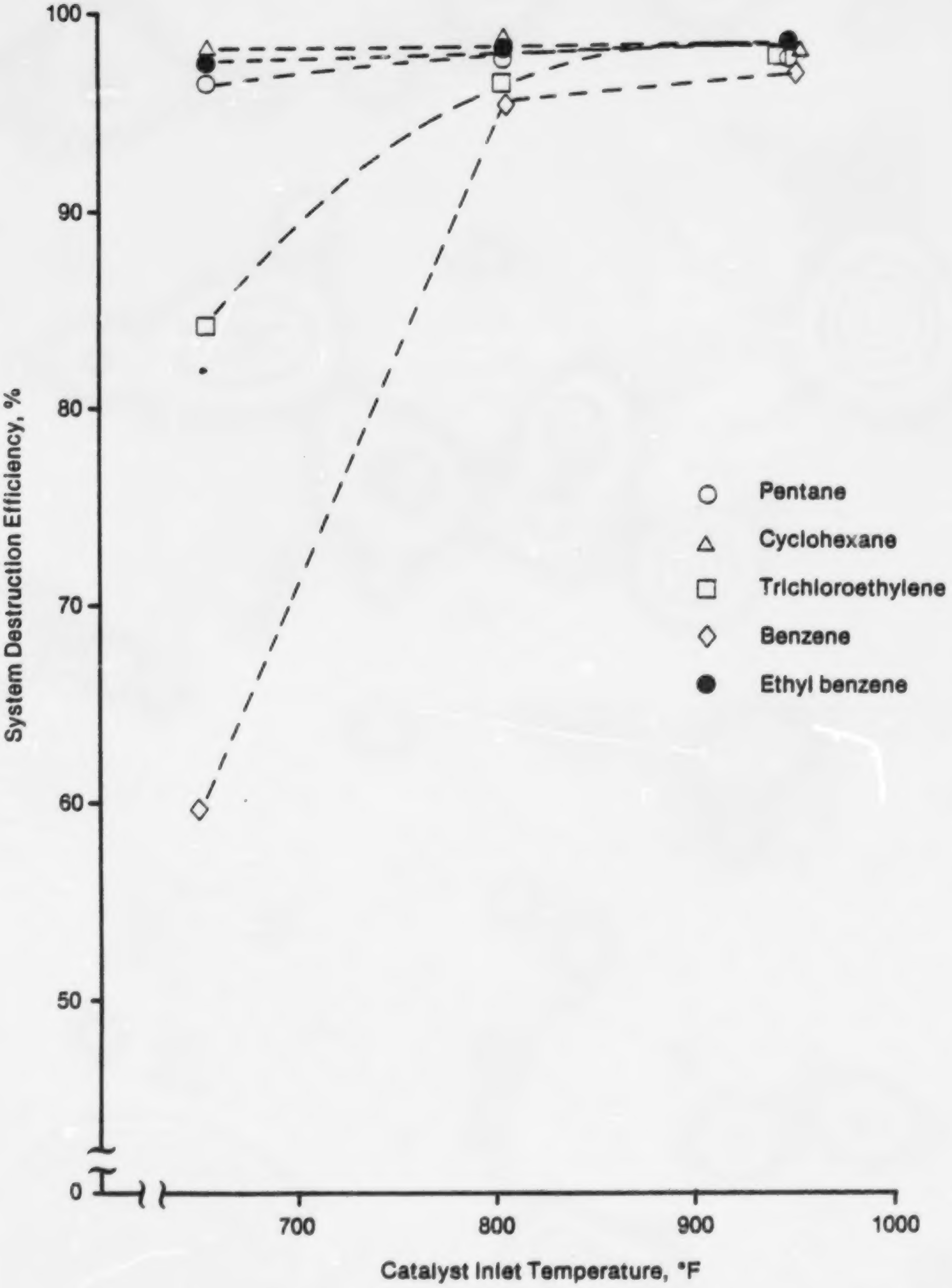

Figure 7-9. Component System Destruction Efficiency As A Function of Catalyst Inlet Temperature For Mixture 2 At A Space Velocity of 7,000 $hr^{-1}$.

trichloroethylene in each of the four test mixtures. System and catalyst destruction efficiencies for trichloroethylene at different temperatures and in different mixtures are presented in Table 7-3. The analysis of covariance technique (ANCOVA) discussed in Section 6.0 was used to assess the effects of mixture on destruction efficiency. Mean destruction efficiencies for each temperature were adjusted for differences in inlet concentration, space velocity, and air-to-gas ratio. The test for a statistically significant difference between trichloroethylene destruction efficiencies was based on a 95 percent confidence interval generated for the adjusted mean values. If the confidence intervals did not overlap the effect of mixture was considered significant. If the intervals did overlap, no conclusion could be made regarding the presence or absence of an effect.

As shown in Table 7-3, the only condition for which an effect of mixture composition was observed was at a catalyst inlet temperature of 650°F. At this temperature, the system destruction efficiency for trichloroethylene was significantly lower in Mixture 2 compared to Mixtures 1 and 4.

## 7.3 RELATIVE COMPOUND DESTRUCTABILITY

Destruction efficiencies measured for the 10 test compounds were compared on the basis of mean and statistically adjusted mean values. The relative destructability of the 10 compounds is presented in Table 7-4. Mean and adjusted mean destruction efficiencies for two catalyst inlet temperatures are presented. Mean destruction efficiencies for each temperature were adjusted for differences in inlet concentration, space velocity and air-to-gas ratio using the ANCOVA technique (see Section 6.0). The compounds are listed in the order of decreasing ease of destructability.

As shown in Table 7-4, the compounds most easily destroyed by the fluidized-bed catalytic system were cyclohexane, ethylbenzene, and pentane, all of which are non-chlorinated hydrocarbons. Benzene and tetrachloroethylene were the most difficult to destroy of the 10 compounds tested.

TABLE 7-3. COMPARISON OF TRICHLOROETHYLENE SYSTEM AND CATALYST EFFICIENCIES IN DIFFERENT MIXTURES

| Catalyst Inlet Temperature[a] (°F) | Mixture | Avg. Inlet Conc. (ppmv) | Avg. Space Velocity | Avg. Air To Gas Ratio | Test Runs | Trichloroethylene System Destruction (%) |  | Statistically Significant Differences[c] | Trichloroethylene Catalyst Destruction (%) |  | Statistically Significant Differences[c] |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Mean[b] | Adjusted Mean |  | Mean | Adjusted Mean[b] |  |
| 650 | 1 | 5.42 | 10,300 | 24.0 | B-3 | 86.0 | 85.8 | Yes, Mixture 2 is significantly lower than Mixtures 1 & 4. | 79.3 | 78.6 | No |
|  | 2 | 2.68 | 9,295 | 24.5 | B-9, B-10 | 80.1 | 79.8 |  | 77.4 | 76.6 |  |
|  | 3 | 2.31 | 9,325 | 24.0 | B-25, B-26 | 83.0 | 81.9 |  | 81.1 | 79.4 |  |
|  | 4 | 11.6, 48.3[d] | 9,250 | 23.5 | B-16, B-17, B-20, B-22 | 83.2 | 82.9 |  | 79.5 | 78.7 |  |
| 800 | 1 | 7.26 | 9,400 | 20.5 | B-4, B-5, B-15, B-29 | 94.9 | 93.8 | No | 91.6 | 90.3 | No |
|  | 2 | 3.18 | 10,450 | 16.0 | B-8, B-11,[e] B-14 | 95.4 | 94.6 |  | 93.1 | 93.6 |  |
|  | 3 | 1.83 | 6,970 | 24.0 | B-27[e] | 95.9 | 92.9 |  |  |  |  |
| 950 | 1 | 7.00 | 8,265 | 17.0 | B-6, B-7 | 98.8 | 97.2 | No | 97.5 | 96.3 | No |
|  | 2 | 3.28 | 8,010 | 19.5 | B-12, B-13 | 98.3 | 96.6 |  | 97.6 | 95.9 |  |
|  | 3 | 1.71 | 8,515 | 15.5 | B-28 | 97.5 | 95.0 |  | 95.2 | 93.2 |  |
|  | 4 | 12.4, 53.4[d] | 8,652 | 18.2 | B-18, B-19, B-23 | 97.8 | 97.2 |  | 96.1 | 95.7 |  |

[a] Nominal or desired temperature. Actual values of test runs included in the statistical analysis may have varied by up to 18°F from the desired temperatures.

[b] Mean destruction efficiencies adjusted for concomittent variables of catalyst inlet concentration, space velocity, and air:gas ratio.

[c] Based on the analysis of covariance results, does mixture have a significant effect on destruction efficiency at the 95% probability level.

[d] The first value is the average for the baseline inlet concentration, the second value is the average of the high inlet concentration.

[e] For those test conditions, catalyst destruction efficiency was not measured.

NOTE: "System destruction" refers to pre-heater plus catalyst destruction while "catalyst destruction" refers only to the catalyst bed with the effect of the preheater not considered.

TABLE 7-4. RELATIVE DESTRUCTABILITY OF TEST COMPOUNDS

| | Destruction Efficiency at 650°F | | Destruction Efficiency at 950°F | |
|---|---|---|---|---|
| | Mean[a] | Adjusted Mean[b] | Mean[a] | Adjusted Mean[b] |
| Cyclohexane | 99 | 99 | 99+ | 99 |
| Ethylbenzene | 98 | 100 | 99+ | 100 |
| Pentane | 96 | 98 | 99+ | 99 |
| Vinyl Chloride | 93 | N/E[c] | 99 | N/E |
| Dichloroethylene | 85 | 92 | 98 | 100 |
| Trichloroethylene[d] | 83 | 83 | 98 | 97 |
| Dichloroethane | 81 | 82 | 99 | 98 |
| Trichloroethane | 79 | 79 | 99 | 99 |
| Benzene | 55 | N/E | 95 | N/E |
| Tetrachloroethylene | 52 | 54 | 92 | 91 |

[a] Based on all destruction efficiencies measured for the specific compound at the nominal or desired temperature.

[b] Mean destruction efficiencies adjusted for concomittant variables of catalyst inlet temperature, space velocity and air-to-gas ratio.

[c] N/E = not estimated due to insufficient data to fully characterize covariate effects.

[d] Based on data for all 4 mixtures.

## 7.4 EFFECT OF INLET CONCENTRATION

Tests to assess the effect of inlet concentration on destruction efficiency were conducted for Mixture 4 at a space velocity of 10,500 $hr^{-1}$. The "low" concentration tests were conducted with each of the four compounds in Mixture 4 at concentrations of 10 ppmv. The "high" concentration tests were performed with each compound at a concentration of 50 ppmv. System destruction efficiencies for Mixture 4 at the high and low concentrations are summarized in Table 7-5. No effect of inlet concentration was found for total mixture destruction or component specific destruction over the range of concentrations tested.

## 7.5 PRODUCTS OF INCOMPLETE OXIDATION

Test results relating to products of incomplete oxidation include gas chromatography/mass spectrometry (GC/MS) and carbon monoxide (CO) results for incinerator outlet samples. These test results are discussed in the sections below.

### 7.5.1 GC/MS Results

Tenax-GC resin samples for three of the four test mixtures were analyzed by the U.S. Air Force Laboratories at Tyndall AFB to identify products of incomplete oxidation. Compounds found in the samples were quantitated against a tenax-GC resin trap with known quantities of Mixture 4 components. The tenax-GC trap used for quantitation was loaded by Radian using the commercially prepared standard available for Method 18 calibrations. Two blank traps were also analyzed by GC/MS. Compounds found on the blanks, which included freon, methylene chloride, benzene, and toluene, were considered to be contaminants of the resin and were not treated as products of incomplete oxidation.

Results from the GC/MS analyses are summarized in Table 7-6. Products of incomplete oxidation included:

## TABLE 7-5. EFFECT OF INLET CONCENTRATION ON MIXTURE 4 DESTRUCTION EFFICIENCY

| Test Run | Catalyst Inlet Temperature °F | Space Velocity ($hr^{-1}$) | Inlet Concentration[a] (ppmv) | System Destruction Efficiency (%) |
|---|---|---|---|---|
| B-17 | 653 | 10,600 | 50.2 | 0.72 |
| B-22 | 660 | 11,200 | 192 | 0.72 |
| B-19 | 953 | 10,200 | 57.1 | 0.97 |
| B-23 | 953 | 10,200 | 216 | 0.95 |

[a] Total inlet concentration for all species.

TABLE 7-6. SUMMARY OF GC/MS ANALYSES FOR PRODUCTS OF INCOMPLETE OXIDATION

| Mixture | Catalyst Operating Temperature (°F) | Space Velocity ($hr^{-1}$) | Test Number | Sample | Produtts Of Incomplete Oxidation (ppmv)[a] |  | Mixture Compounds[b] (ppmv) |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | 1,2 Dichloroethylene |  | 1,2 Dichloroethane | Trichloroethylene | 1,1,2-Trichloroethane | Tetrachloroethylene |
| 4 | 650 | 7,000 | B-20 | GC/MS | 0.73 |  | 1.99 | 1.50 | 1.73 | 2.20 |
|  |  |  |  | GC/FID |  |  | 1.35 | 1.04 | 1.43 | 3.51 |
|  |  |  |  | Tenax-GC |  |  | 1.70 | 1.53 | 1.73 | - |
|  | 950 | 7,000 | B-18 | GC/MS | 0.09 |  | 0.03 | 0.15 | 0.07 | 0.38 |
|  |  |  |  | GC/FID |  |  | 0.07 | 0.17 | 0.13 | 0.76 |
|  |  |  |  | Tenax-GC |  |  | 0.04 | 0.12 | 0.05 | 0.35 |
|  |  |  |  |  |  |  | Dichloroethylene | Trichloroethylene |  |  |
| 1 | 800 | 10,500 | B-15 | GC/MS |  |  | 2.32 | 1.18 |  |  |
|  |  |  |  | GC/FID |  |  | 0.82 | 0.27 |  |  |
|  |  |  |  |  | 1,1,1 tri-chloroethane | Tetrachloro-ethylene | Vinyl Chloride | Trichloroethylene |  |  |
| 3 | 650 | 10,500 | B-26 | GC/MS |  |  | Trace | 0.95 |  |  |
|  |  |  |  | GC/FID |  |  | 0.69 | 0.34 |  |  |
|  | 950 | 7,000 | B-24 | GC/MS | 0.03 | 0.01 | ND | 0.05 |  |  |
|  |  |  |  | GC/FID |  |  | 0.07 | <0.08 |  |  |

[a] All samples were analyzed for vinyl chloride, 1,2 dichloroethylene, 1,2 dichloroethane, 1,1,1 trichloroethane, trichloroethylene, 1,1,2 tirchloroethane, and tetrachloroethylene; however, a value is indicated for products of incomplete combustion only if the compound was detected.

[b] The GC/MS was calibrated with a Tenax-GC trap loaded with a known amount of Mixture 4. The calibration tube was loaded with: 1,2 dichloroethane, 6,633 ng; trichloroethylene, 9,350 ng; 1,1,2-trichloroethane, 8,562 ng; tetrachloroethylene, 11,866 ng. For 1,2 dichloroethylene and 1,1,1-trichloroethane, the response factor for 1,2 dichloroethane was used for quantitation.

ND = not detected at 0.01 ppmv.

- 1,1,1-trichloroethane (0.03 ppmv) and tetrachloroethylene (trace to 0.01 ppmv) from Mixture 3 components, and
- 1,2-dichloroethylene (0.09 to 0.73 ppmv) from Mixture 4 components.

No other products of incomplete combustion were identified at the estimated detection limit of 0.01 ppmv.

Quantities of test compounds found by GC/MS in each of the three mixtures are also presented in Table 7-6 for comparison with the Method 18 and tenax-GC sampling/analysis results. With the exception of vinyl chloride for Mixture 3, the three methods agree fairly well at most test conditions.

### 7.5.2 Carbon Monoxide Emissions

Carbon monoxide concentrations in the incinerator outlet gas are shown for all four mixtures in Figure 7-10 as a function of catalyst inlet temperature and air-to-gas ratio. As shown in Figure 7-10, CO concentrations decrease with increasing temperature. At a given temperature, the CO concentration decreases with increasing air-to-gas ratio.

Approximately 50 percent of the CO found in the incinerator outlet gas can be attributed to the incomplete combustion of natural gas in the preheater flame. This estimate is based on CO measurements taken before and after VOC/HAP test mixtures were injected. The remaining CO is formed from incomplete oxidation of VOC/HAP in the inlet gas stream. In reviewing the CO results, no trend was observed for CO emissions as a function of mixture composition.

## 7.6 POTENTIAL HCl EMISSIONS

Concentrations of hydrochloric acid (HCl) and chlorine ($Cl_2$) in the incinerator outlet gas were not measured during this test program. To provide a basis for predicting HCl emissions from Mixtures 1, 2, and 3, theoretical HCl concentrations and emission rates were calculated assuming that each chlorine atom in the inlet gas stream forms a molecule of HCl (i.e., assuming complete oxidation).

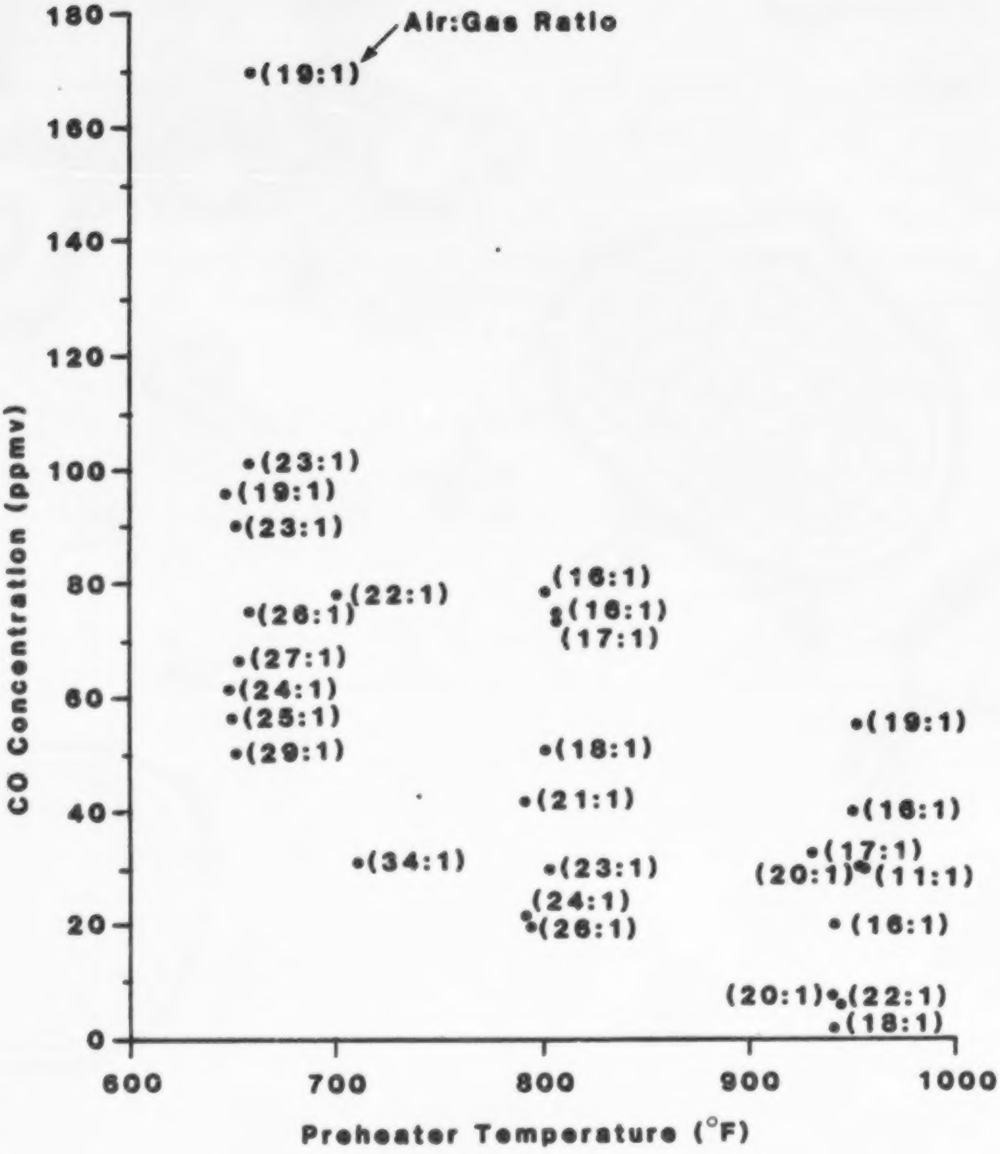

Figure 7-10. CO Concentration at the outlet stack as a function of preheater temperature for all test runs.

Results of these calculations are presented in Table 7-7. The HCl concentrations are based on a catalyst inlet temperature of 800°F and an air-to-gas ratio of 20:1. The emission rates shown are for a total inlet gas flow rate of 1,000 scfm.

As shown in Table 7-7, HCl concentrations for the assumed operating conditions range from 6.3 to 28.1 ppmv for the three mixtures. The corresponding HCl emission rates for a 1,000 scfm system range from 0.06 to 0.3 lb/hr.

## 7.7 COMPARISON OF METHOD 18 AND TENAX-GC DATA

Mixture and compound specific system destruction efficiencies measured according to Method 18 and the tenax-GC method were compared for all test conditions where both measurements were made. Results of this comparison showed average differences in compound destruction efficiencies ranging from 0.2 to 1.4 percent for all species except benzene. Results for benzene showed an average difference of 6.4 percent for destruction efficiencies based on the two methods. Average differences between Method 18 and tenax-GC destruction efficiencies for mixtures were 0.7, 0.3, and 0.7 percent for Mixtures 1, 2, and 4, respectively.

## TABLE 7-7. THEORETICAL HCL CONCENTRATIONS IN OUTLET GAS FOR MIXTURES 1, 2, AND 3

| Mixture Designation | Mixture Compounds | Inlet Concentration (ppmv) | Theoretical HCL Concentration In Outlet Gas | |
|---|---|---|---|---|
| | | | ppmv[a] | lb/hr @ 1000 scfm |
| Mixture 1 | Trichloroethylene | 6.3 | 28.1 | 0.3 |
| | 1,2 dichloroethylene | 8.5 | | |
| Mixture 2 | Trichloroethylene | 2.7 | 6.3 | 0.06 |
| | Benzene | 1.5 | | |
| | Ethylbenzene | 5.6 | | |
| | Pentane | 11.5 | | |
| | Cyclohexane | 14.1 | | |
| Mixture 3 | Vinyl Chloride | 7.5 | 10.1 | 0.09 |
| | Trichloroethylene | | | |

[a] This concentration is calculated assuming an air gas ratio of 20:1 and that the 1,000 scfm inlet air stream is heated from 68°F to 800°F. The concentration represents the total HCl from each mixture.

# 8.0 UV-CATALYTIC OXIDIZER RESULTS

The UV-catalytic oxidizer testing characterized performance of the oxidizer for one test mixture with and without ozone addition. The effects of inlet concentration, space velocity, and humidity were also investigated. Test results without ozone showed compound destruction efficiencies ranging from 16 to 67 percent over a wide range of space velocities. With ozone, complete oxidation of the test mixture components was achieved, but high concentrations of several unidentified reaction products were observed.

Results of tests conducted without ozone addition are discussed in Section 8.1 and results of tests with ozone addition are discussed in Section 8.2.

## 8.1 OXIDATION WITHOUT OZONE

Destruction efficiencies for the UV-catalytic oxidizer without ozone addition are summarized in Table 8-1. Data are shown in Table 8-1 for three different space velocities, two levels of humidity and two mixture inlet concentrations. Comparison of results for different test conditions indicates that the single most important parameter affecting the destruction efficiency is space velocity. The highest mixture destruction measured was 64 percent, at a space velocity of 200 $hr^{-1}$.

## 8.2 OXIDATION WITH OZONE

Destruction efficiencies for the UV-catalytic system with ozone addition are summarized in Table 8-2. As shown in Table 8-2, destruction efficiencies for dichloroethylene and trichloroethylene were greater than 99 percent. However, three unknown reaction products totaling approximately 2 ppmv (quantitated as trichloroethylene) were detected in the oxidizer

TABLE 8-1. SUMMARY OF MIXTURE 1 RESULTS WITHOUT OZONE[a]

| Test Run(s) | Compound | Inlet Concentration (ppmv) | Space Velocity ($hr^{-1}$) | Humidity Level (lb $H_2O$/ lb Dry Air) | Destruction Efficiency (%) | Outlet CO Concentration (ppmv) |
|---|---|---|---|---|---|---|
| A-2, A-3 | Dichloroethylene | 5.99 | 3,000 | Ambient | 16 | 1.3 |
| | Trichloroethylene | 3.82 | | (0.0133) | 23 | |
| | TOTAL | 9.92 | | | 19 | |
| A-4, A-5, A-6 | Dichloroethylene | 6.43 | 800 | Ambient | 29 | 3.0 |
| | Trichloroethylene | 4.12 | | (0.0138) | 36 | |
| | TOTAL | 10.6 | | | 32 | |
| A-7, A-9 | Dichloroethylene | 5.18 | 800 | High[b] | 30 | 2.3 |
| | Trichloroethylene | 3.28 | | (0.0144) | 44 | |
| | TOTAL | 8.46 | | | 35 | |
| A-8 | Dichloroethylene | 1.91 | 800 | High | 36 | 0.5 |
| | Trichloroethylene | 0.95 | | (0.0229) | 25 | |
| | TOTAL | 2.86 | | | 32 | |
| A-10 | Dichloroethylene | 1.80 | 200 | High | 67 | 3.0 |
| | Trichloroethylene | 1.03 | | (0.0150) | 59 | |
| | TOTAL | 2.83 | | | 64 | |

[a] All tests conducted with a catalyst temperature between 80 and 96°F.

[b] Operation at the higher humidity was performed by vaporizing water into the inlet gas stream. Water injection generally increased humidity to about 1.5 times ambient.

TABLE 8-2. SUMMARY OF MIXTURE 1 RESULTS WITH OZONE[a]

| Test Run | Compound (Retention Time) | Inlet Concentration (ppmv) | Outlet Concentration (ppmv) | Humidity Level (lb $H_2O$/lb Dry Air) | Destruction Efficiency (%) | UV Lights (On - Off) |
|---|---|---|---|---|---|---|
| A-12 | Dichloroethylene | 4.66 | ND[b] | 0.0150 | 99+ | On |
| | Trichloroethylene | 2.88 | ND | | 99+ | |
| | Unknown (1.04)[c] | - | 1.2 | | - | |
| | Unknown (1.59) | - | 0.36 | | - | |
| | Unknown (1.90) | - | 0.43 | | - | |
| | TOTAL | 7.54 | 1.99 | | 74 | |
| A-13 | Dichloroethylene | 4.83 | ND[b] | 0.0150 | 99+ | On |
| | Trichloroethylene | 2.99 | ND | | 99+ | |
| | Unknown (1.0) | - | 1.0 | | - | |
| | Unknown (0.34) | - | 0.34 | | - | |
| | Unknown (0.52) | - | 0.52 | | - | |
| | TOTAL | 7.82 | 1.86 | | 76 | |
| A-14 | Dichloroethylene | 4.83 | ND[b] | 0.0150 | 99+ | Off |
| | Trichloroethylene | 2.88 | ND | | 99+ | |
| | Unknown (1.1) | - | 1.1 | | - | |
| | Unknown (0.32) | - | 0.32 | | - | |
| | Unknown (0.60) | - | 0.60 | | - | |
| | TOTAL | 7.71 | 2.02 | | 74 | |

[a] All tests conducted with catalyst operating temperature of 88°F.

[b] ND = not detected at 0.03 ppmv detection limit.

[c] Unidentified compound quantitated as trichloroethylene. GC column retention time given in parentheses.

outlet gas. Including the unknown species, total mixture destruction efficiency was approximately 75 percent for tests conducted at space velocities of 3,000 and 800 $hr^{-1}$. One additional test conducted without UV lamps showed 74 percent overall destruction. During the ozone testing, concentrations of ozone in the inlet gas stream were approximately 140 to 440 ppmv, depending on the inlet gas flowrate.

Samples from one test condition were analyzed by GC/MS in an effort to identify the unknown reaction products. No chlorinated reaction products were found, but two non-chlorinated products were identified as methyl formate and methyl acetate.

Since mixture destruction efficiencies without ozone were below desired levels and high concentrations of several reaction products were observed with ozone, a decision was made to discontinue testing of the UV-catalytic system.

# 9.0 CONCLUSIONS AND RECOMMENDATIONS

## 9.1 CONCLUSIONS

Conclusions resulting from tests conducted on the two catalytic systems are discussed separately in the sections below.

### Fluidized-Bed Incinerator

Three general conclusions relating to catalytic incineration technology can be made based on results from the fluidized-bed incinerator:

1. Overall destruction efficiencies in the 97 to 99 percent range are achievable with catalytic incineration for chlorinated hydrocarbon mixtures.
2. Catalytic incineration may be a viable option for the control of VOC/HAP emissions in off-gases from contaminated groundwater air strippers.
3. Destruction in the preheater contributes substantially to the overall system destruction efficiency and performance may, therefore, be enhanced by preheater designs that provide for optimum contacting between the flame zone and the inlet gas stream.

Other conclusions from the fluidized-bed incinerator are listed below. These findings are more specific to the catalyst, compounds, and conditions tested in this study.

- The destruction efficiency of chlorinated hydrocarbons is a strong function of catalyst inlet temperature and a weak function of space velocity.
- Component specific destruction efficiencies vary widely for different compounds. The presence of a single compound that is difficult to destroy may lower overall mixture destruction substantially.

- Chlorinated products of incomplete oxidation are similar in structure to compounds in the inlet gas stream. These compounds are at relatively low concentrations (0.01 to 0.09 ppmv) at temperatures giving high overall destruction efficiencies (i.e., >95 percent).
- Carbon monoxide concentrations from the fluidized-bed system are low, ranging from 100 to 1 ppmv.
- Component inlet concentration has no effect on compound specific destruction efficiency between 10 and 50 ppmv.

UV-Catalytic Oxidizer

The UV-catalytic oxidizer testing showed that unreasonably long gas residence times are required for this system to achieve acceptable destruction efficiencies of chlorinated hydrocarbon mixtures without ozone addition. Essentially complete destruction of dichloroethylene and trichloroethylene (99+ percent) can be achieved with ozone addition, but high concentrations of reaction products are observed. Further work with this system to characterize the reaction products and improve overall destruction efficiencies is needed before the UV-catalyst oxidizer would be considered appropriate for controlling VOC/HAP emissions.

## 9.2 RECOMMENDATIONS

Based on the encouraging results obtained for the fluidized-bed catalytic incinerator, further investigation of this system for application to groundwater air strippers is warranted. The next logical step is to demonstrate applicability of the system through relatively long-term operation on real stripper off-gas. Costs associated with this testing could be minimized by using the pilot-scale test system as opposed to purchasing a full-scale unit.

The site for the demonstration testing should be selected to provide a multi-component mixture with one or more compounds that are expected to be difficult to destroy. The first phase of the testing should involve a short parametric test to optimize the system for a target mixture destruction efficiency. Operation at the selected conditions for a period of several months, with intermittent sampling, could then be conducted to assess long-term operating effects on the catalyst. Depending on the incinerator inlet concentrations and the target destruction efficiency, sampling for VOC/HAP should be performed using Method 18 and/or the volatile organic sampling train (VOST).

# 10.0 REFERENCES

1. Palazzolo, M. A., et al. Parametric Evaluation of VOC/HAP Destruction via Catalytic Incineration. (Prepared for U.S. Environmental Protection Agency, Research Triangle Park, N.C. EPA-600/2-85-041, NTIS No. PB85-191187/A7, April 1985.)

2. SAS Institute, Inc. SAS User's Guide, 1982 Edition. Cary, N.C. SAS Institute, Inc., 1982.

3. Brownlee, K. A. Statistical Theory and Methodology in Science and Engineering. John Wiley & Sons, Inc. New York, 1965.

# APPENDIX A

# QUALITY ASSURANCE/QUALITY CONTROL RESULTS

The test approach used in the pilot-scale investigation of catalytic oxidation incorporated a comprehensive quality assurance/quality control (QA/QC) program as an integral part of the overall test program. The QA/QC program was designed to ensure that data collected would be complete, representative, and comparable to other similar data. It was also designed to control measurement data quality within prescribed limits of acceptability, and to ensure that the resulting data were of known quality with respect to precision and accuracy.

This section presents an assessment of the quality of the measurement data collected during this test program. This assessment is based upon QC data and performance audit results, and provides estimates of the uncertainty associated with the measurement data. Section A.1 presents conclusions and a brief summary of key QA/QC results.* A discussion of the objectives of the QA/QC efforts and the general approach used in achieving these objectives is presented in Section A.2. Performance audit procedures and results are presented and discussed in Section A.3. Section A.4 addresses QC procedures and results.

## A.1 SUMMARY AND CONCLUSIONS

Quality control data collected throughout the course of the measurement program, along with the performance audit results, provide the basis for assessing the quality of VOC/HAP destruction efficiency data. Performance audit results indicate that for both Method 18 data (i.e., destruction efficiency data where Method 18 was used for both inlet and outlet VOC measurements) and for Tenax data (i.e., destruction efficiency data where outlet measurements were made using the Tenax sampling/analytical method), uncertainty in the measured destruction efficiency decreases with increasing destruction efficiency. For test conditions achieving ≥90% destruction efficiency, overall uncertainty in the measured destruction efficiency values is typically less than ±5%, except for benzene results by Method 18. Method 18 benzene data exhibited unusually high measurement error. Overall, Tenax destruction efficiency data exhibited significant positive bias, while a significant negative bias was observed for Method 18 benzene data.

---

*Independent audits were performed on this study by Research Triangle Institute under an EPA subcontract. The audit results were rated "acceptable" by the EPA Quality Assurance Officer.

Audit results for Method 18 VOC concentration measurements indicate relative error (bias) in these measurements to be within ±30% while error for Tenax measurements was generally somewhat less at ±25%. Overall better performance of Method 18 may be attributed largely to significantly better observed precision of 5% as compared to 20% for the Tenax method.

Carbon monoxide measurements were found to be accurate within ±2% (i.e., bias ≤2%) of the full-scale value. Precision of the CO data was observed to be better than 4% in terms of day-to-day variability.

Table A-1 summarizes measured values for precision and bias of the various measurements. Precision and bias objectives which were presented in the QA Project Plan for this project are shown for comparison. The data quality measurements provided in Table A-1 are average values and, as such, provide only a cursory glimpse of the data quality assessment performed for this project. The QA/QC program was designed to provide detailed information pertaining to the limitations associated with the measurement data. While the performance audit results and QC data presented in the remainder of this section provide the primary basis for evaluation of uncertainty in the emission rate measurements, this evaluation requires careful interpretation of the audit and QC data in the context of the measurement data and the manner in which the individual measurement parameters are related.

## TABLE A-1. SUMMARY OF ESTIMATED VERSUS MEASURED DATA QUALITY

| Measurement Parameter | Method | Precision[a] |  | Bias[b] |  |
|---|---|---|---|---|---|
|  |  | Estimated[c] | Measured | Estimated[c] | Measured[d] |
| Overall VOC Destruction Efficiency (Calculated based on inlet and outlet concentrations) | Method 18 (modified) | 10% | e | - |  |
|  | Benzene |  |  |  | -1.61<br>(-35.3,4.3) |
|  | Pentane |  |  |  | -0.09<br>(-17.7,8.7) |
|  | Trichloroethylene |  |  |  | 0.60<br>(-9.0,22.3) |
|  | Tenax | 10% | e | - |  |
|  | Benzene |  |  |  | 0.95<br>(0.13,37.9) |
|  | Pentane |  |  |  | 0.63<br>(0.11,22.3) |
|  | Trichloroethylene |  |  |  | 0.80<br>(0.16,11.1) |
| VOC Concentration (individual species and total VOC) | Method 18 (modified) | 20% | 5% | ±20% | ±30% |
| Outlet VOC Concentration (individual species and total VOC) | Tenax resin sampling train/Method 601 | 20% | 20% | ±25% | ±25% |
| Carbon Monoxide Concentration | Continuous CO monitor | 5% | 4% | ±5%[f] | 2% |

---

[a] Coefficient of variation (%) for repeat analyses (day-to-day variability).

[b] Bias (systematic error), expressed as a percentage of the measured value (i.e., relative error). Median values and 95% bounds are presented for destruction efficiency bias estimates; see Section A.3.

[c] Data quality objective presented in the Quality Assurance Project Plan.

[d] Measured bias based on QA performance audit results.

[e] Program objectives required comparisons of average DE measured under different conditions. Destruction efficiency data are presented in terms of confidence limits which reflect uncertainty in the measurement data. Statistical techniques used to assess and validate data are described in detail in Sections 6 and A.3.

[f] Bias for CO concentration expressed as a percentage of the instrument span value (i.e., full scale).

## A.2 QA/QC PROGRAM OBJECTIVES

For any measurement effort, there always exists some degree of uncertainty associated with the measurement data due to inherent limitations of the measurement system. The utility of the measurement data is dependent upon the degree to which the magnitude of this uncertainty is known and upon its relative impact. The pilot-scale catalytic incinerator testing described in this report included a comprehensive quality assurance/quality control (QA/QC) program. The objectives of the QA/QC effort were twofold. First, they provided the mechanism for controlling data quality within acceptable limits. Second, they formed the basis for estimates of uncertainty by providing the necessary information for defining random error limits associated with the measurement data.

The quality assurance function was organized to provide independent review and assessment of project activities and their ability to achieve the stated data quality objectives. The QA Coordinator for this project had the responsibility of evaluating the adequacy and effectiveness of the QC system and providing assurance that it was, in fact, responsive to the specific needs of the program.

In addition to reviewing the test plan and providing input into the design of the QC efforts, the QA Coordinator implemented both a performance and systems audit during the test program. The performance audit was designed to provide a direct, quantitative, point-in-time assessment of data quality in terms of accuracy. This was achieved by using equipment and standards which were independent of those used by the laboratory personnel. The systems audit was designed to provide a systematic, qualitative review and assessment of the critical elements of the various measurement systems and associated internal quality control (QC) systems, with emphasis upon procedures and documentation. Together, the QC data and the audit results may be used to qualify the measurement data, as discussed in the remainder of this section.

## A.3 QUALITY ASSURANCE AUDITS

As part of the quality assurance effort for this project, a QA audit was conducted during the fluidized bed incinerator testing. The audit addressed both VOC measurement systems and the CO monitor. The audit was performed by QA personnel using audit standards which were separate from those used for day-to-day testing. Audit procedures and results are discussed below.

### A.3.1 VOC Measurements

Destruction efficiency was determined for the various test mixtures used in this program by measurements of organic vapor concentration in the incinerator inlet and outlet gas streams. Two independent methods were used for measuring volatile organic compound (VOC) concentration: Method 18 (modified) and Tenax Resin Sampling Train/GC/FID analysis. Modified Method 18 sampling/analysis was performed at both the inlet and outlet of the incinerator (and preheater). Tenax sampling was performed at the outlet to facilitate measurement of very low sample concentrations. For each test condition, separate destruction efficiency values were calculated using Method 18 and Tenax resin results.

Modified Method 18 analyses were performed using a Shimadzu 6AM gas chromatograph with flame ionization detection. These analyses were performed "on-line" during incinerator testing. Samples were delivered to the GC via a heated sample line and a heated, stainless steel pump located upstream of the sample line. Separate pumps and sample lines were used for the inlet and outlet sampling locations. Analyses of Tenax resin tube samples collected at the incinerator outlet were performed on a Varian 3400 gas chromatograph equipped with dual packed columns and dual flame ionization detectors (FID). Samples were analyzed by thermally desorbing VOCs collected on the Tenax resin, cryofocusing with liquid nitrogen at -150°C, followed by flash vaporization (180°C) to the GC columns.

The performance audit of the Method 18 and Tenax resin analyses was designed to fulfill two objectives. First, it was designed to provide estimates of bias in measured VOC concentrations. Second, and more importantly, the audit was designed to provide data which could be used to estimate uncertainty in calculated destruction efficiencies. Since destruction efficiency represents a ratio between inlet and outlet VOC mass flow rates, bias in measured (i.e., calculated) destruction efficiency is a function of relative bias between inlet and outlet mass flow rate measurements. Error, or uncertainty, associated with any given destruction efficiency value reflects the combined effects of systematic error, or bias, and random error, or measurement variability. Since mass flow is calculated from separate measurements of concentration and flow rate, errors associated with both measurements must be considered in estimating overall uncertainty. Also, interaction of inlet and outlet measurement error, which are independent of each other, must be considered in estimating uncertainty in calculated destruction efficiencies.

The first objective of the performance audit was to quantitate bias in measured VOC concentrations for both Method 18 and Tenax resin analyses. This part of the audit consisted of challenging the VOC measurement systems with multiple concentrations of a standard gas mixture. Since it was not practical to perform the audit using all the species used in the test program, a mixture containing trichloroethylene, pentane, and benzene was chosen as representative of the species of interest.

The audit gas mixture was obtained from Scott Environmental Technology (vendor certified, ±2% accuracy). Multiple concentrations were obtained by dynamic dilution of the cylinder gas standard using a capillary dilution system. The dilution system was calibrated at each flow used immediately prior to the audit using an NBS traceable bubble flow meter. The diluted audit gas mixtures were delivered to the GC used for modified Method 18 analyses via the normal sample line and pump used for incinerator testing. Tenax tube samples were collected by operating the VOST sampling train in the normal manner.

For both modified Method 18 and Tenax trap analyses, each component of the sample gas stream was quantitated separately. Quantitation was based on instrument response as compared to a previously established response factor. For modified Method 18 analyses, this response factor was determined daily, based on calibration against standard gas mixtures of known concentration. Thus, one source of bias in measured sample concentrations would be calibration error due to error in values used to calculate gas phase concentration of the calibration standard. Bias could also be introduced through losses in the sample line and/or pump. Modified Method 18 data for the cylinder gas audit are summarized in Tables A-2 through A-4. Tenax trap data are presented in Table A-5.

As indicated in Tables A-2 through A-4, average error for pentane by modified Method 18 was within the ±20% objective at -7.2%, while average error for both benzene and trichloroethylene exceeded the ±20% objective for this method. Trichloroethylene results were biased low, with an average error of -30%. Benzene results showed a positive bias of approximately the same magnitude. Results for all three audit species showed excellent linearity over the audit range, with correlation coefficients exceeding 0.9990. The audit data also indicated precision for all three species to be within the ≤20% objective, as indicated by pooled CVs for the audit data.

Tenax tube audit data, summarized in Table A-5, indicate approximately comparable error for all three species, averaging -31% over the two concentrations tested. The ±25% accuracy and ±20% precision objectives for this measurement technique were not achieved at both concentrations used in the audit for any of the three test species. The precision for all three species averaged 23% as indicated by the pooled CV.

The second objective of the performance audit was to estimate overall uncertainty in the destruction efficiency measurements. As discussed above, this overall uncertainty reflects the combined effects of uncertainty in the individual measurements of concentration and flow rate at the inlet and outlet of the system. Since it is not possible to directly assess relative

TABLE A-2. METHOD 18 AUDIT DATA FOR TRICHLOROETHYLENE

| Input Concentration (ppmv) | Average Measured Concentration (ppmv) | Mean Relative Error[a] (%) | Coefficient of Variation[b] (%) |
|---|---|---|---|
| 0.111 | 0.083 | -25.25 | 6.9 |
| 0.055 | 0.014 | -74.74 | 42.9 |
| 0.288 | 0.197 | -31.71 | 10.6 |
| 0.515 | 0.370 | -28.12 | 12.4 |
| 1.88 | 1.25 | -33.4 | 2.1 |
| 4.18 | 3.15 | -24.5 | 2.6 |
| 10.34 | 8.37 | -19.0 | 2.0 |
| 20.14 | 15.96 | -20.8 | 2.5 |

Overall Mean Relative Error = -30.3%

Pooled Coefficient of Variation = 16.5%

Regression Parameters

Where x = input concentration and y = measured concentration

Slope = 0.798
y-intercept = -0.069
Correlation Coefficient = 0.9995

---

[a] Based on three trials at each concentrations.

[b] Relative standard deviation for three measurements.

## TABLE A-3. METHOD 18 AUDIT DATA FOR PENTANE

| Input Concentration (ppmv) | Average Measured Concentration (ppmv) | Mean Relative Error[a] (%) | Coefficient of Variation[b] (%) |
|---|---|---|---|
| 0.111 | 0.127 | 13.62 | 16.4 |
| 0.055 | 0.040 | -27.82 | 0 |
| 0.288 | 0.273 | -5.09 | 2.1 |
| 0.515 | 0.523 | 1.66 | 5.8 |
| 1.88 | 1.49 | -20.4 | 1.0 |
| 4.18 | 3.73 | -10.7 | 1.2 |
| 10.34 | 9.58 | -7.3 | 0.5 |
| 20.14 | 18.39 | -8.7 | 3.5 |

Overall Mean Relative Error = -7.23%

Pooled Coefficient of Variation = 6.3%

Regression Parameters

Where x = input concentration and y = measured concentration

Slope = 0.916
y-intercept = -0.026
Correlation Coefficient = 0.9994

---

[a] Based on three trials at each concentrations.

[b] Relative standard deviation for three measurements.

## TABLE A-4. METHOD 18 AUDIT DATA FOR BENZENE

| Input Concentration (ppmv) | Average Measured Concentration (ppmv) | Mean Relative Error[a] (%) | Coefficient of Variation[b] (%) |
|---|---|---|---|
| 0.111 | 0.237 | 113 | 14.8 |
| 0.055 | 0.120 | 117 | 30.0 |
| 0.288 | 0.340 | 18.5 | 2.9 |
| 0.515 | 0.590 | 14.4 | 8.1 |
| 1.88 | 1.69 | -9.6 | 0 |
| 4.18 | 4.14 | -0.6 | 1.8 |
| 10.34 | 10.56 | 2.6 | 0.9 |
| 20.14 | 20.08 | 0.1 | 4.4 |

Overall Mean Relative Error = 30.6%

Pooled Coefficient of Variation = 12.3%

Regression Parameters

Where x = input concentration and y = measured concentration

Slope = 1.002
y-intercept = 0.0426
Correlation Coefficient = 0.9991

---

[a] Based on three trials at each concentrations.

[b] Relative standard deviation for three measurements.

## TABLE A-5. SUMMARY OF TENAX AUDIT DATA

| Species | Input Concentration (ppmv) | Average Measured Concentration (ppmv) | Mean Relative Error[a] (%) | Coefficient of Variation[b] (%) |
|---|---|---|---|---|
| Benzene | 0.111 | 0.091 | -17.8 | 23.4 |
| | 0.287 | 0.207 | -28.0 | 23.3 |
| Pentane | 0.111 | 0.086 | -23.2 | 9.8 |
| | 0.288 | 0.194 | -32.8 | 32.3 |
| Trichloroethylene | 0.111 | 0.069 | -38.4 | 18.7 |
| | 0.288 | 0.156 | -45.8 | 26.4 |

Pooled Coefficient of Variation = 23.3%

---

[a] Based on three trials at each concentrations.

[b] Relative standard deviation for three measurements.

accuracy of destruction efficiency measurements as can be done for concentration measurements, for example, a computer simulation was performed to derive estimates of overall error in the destruction efficiency measurements. This simulation was performed using the performance audit results presented above to account for error in measured VOC concentrations. Error contributed by variability in measured flow rates was taken into account by using flow rate data collected during actual incinerator testing.

In this simulation, the audit data and flow rate data were used to calculate destruction efficiency values. This was done using a computerized data reduction scheme in which pairs of VOC audit data were combined as "inlet" and "outlet" concentrations. This was done using Method 18 data as both "inlet" and "outlet" values and also using Method 18 data only as "inlet" values and Tenax data as "outlet" values. In this manner, all possible combinations (based on the audit data) of average "inlet" and "outlet" concentrations were generated. For each "inlet"/"outlet" combination, different destruction efficiency values were calculated using each of the 28 inlet and outlet flow rate measurements made during the actual test series. "Measured" destruction efficiency values were generated using measured concentrations for the audit test mixtures. Corresponding "actual" destruction efficiency values were generated using input (i.e., "actual") concentrations. The difference between "measured" and "actual" destruction efficiency was taken to represent overall measurement error.

An example is helpful to clarify the procedure used. Referring to Table A-3, one input concentration of trichloroethylene was 4.18 ppmv. The average measured concentration at this point was 3.15 ppmv. At a second input concentration, 0.288 ppmv, the average measured concentration was 0.197 ppmv. Using the first pair of values as "inlet" concentrations (actual and measured, respectively) and the second set of values as "outlet" values, and choosing (from actual test data) an inlet to outlet volumetric flow rate ratio of 1.57, resulting calculated values for "actual" and "measured" destruction efficiency are 89.2% and 90.2%, respectively. The relative bias between the "actual" and "measured" destruction efficiency is then 1.1% (i.e., [1-(89.2/90.2)] x 100).

In order to simulate destruction efficiency values which were representative of the test series results, a restriction in the computer simulation routine required that simulated destruction efficiency values be at least 40%.

Results of the computer simulation of uncertainty in measured destruction efficiency are presented in Table A-6. "Method 18" results represent estimates derived using only Method 18 audit data. "Tenax" results represent estimates derived using Method 18 audit data for inlet values and Tenax data for outlet values. The number of simulated cases used for each method and species is indicated in the table. The simulation indicates relatively large negative bias for benzene destruction efficiency measurements by Method 18 and significant positive bias for all Tenax results. The positive bias seen for the Tenax measurements could be a result of using the two independent methods for measuring inlet (Method 18) and outlet (Tenax resin) concentrations, where the Tenax data had consistently poorer recovery than did the Method 18 data (i.e., there was a larger negative bias in the Tenax data).

Figures A-1 through A-6 present plots of the simulation data showing relative error versus destruction efficiency for each of the methods and species. These figures indicate that the bias in measured destruction efficiency decreases as destruction efficiency increases. This trend is evident among all species for both Method 18 and Tenax audit data. The marked decrease in bias for high destruction efficiencies (>90%) can be seen by comparing Tables A-6 and A-7. Table A-7 summarizes the simulation results for cases where the "actual" destruction efficiency was greater than or equal to 90%. For this subset of the data base, only benzene results by Method 18 contained bias estimates which fell outside the ±10% error limits. Again, however, we see a significant negative bias for benzene by Method 18 and a significant positive bias for the Tenax measurements.

TABLE A-6. UNCERTAINTY IN MEASURED DESTRUCTION EFFICIENCY

| Method | Species | Number of Observations Generated | Median % Relative Error | 95% Bounds on Relative Error Estimates[a] | Percent Outside 10% Error Limits |
|---|---|---|---|---|---|
| 18 | Benzene | 640 | -1.61 | (-35.5,4.3) | 22.2 |
| | Pentane | 649 | -0.09 | (-17.7,8.7) | 6.0 |
| | Trichloroethylene | 664 | 0.60 | (-9.0,22.3) | 11.3 |
| Tenax | Benzene | 277 | 0.95 | (0.13,37.9) | 19.1 |
| | Pentane | 277 | 0.63 | (0.11,22.3) | 14.8 |
| | Trichloroethylene | 277 | 0.80 | (0.16,11.1) | 5.1 |

[a] 95% of the generated relative error (% bias) estimates were within these limits.

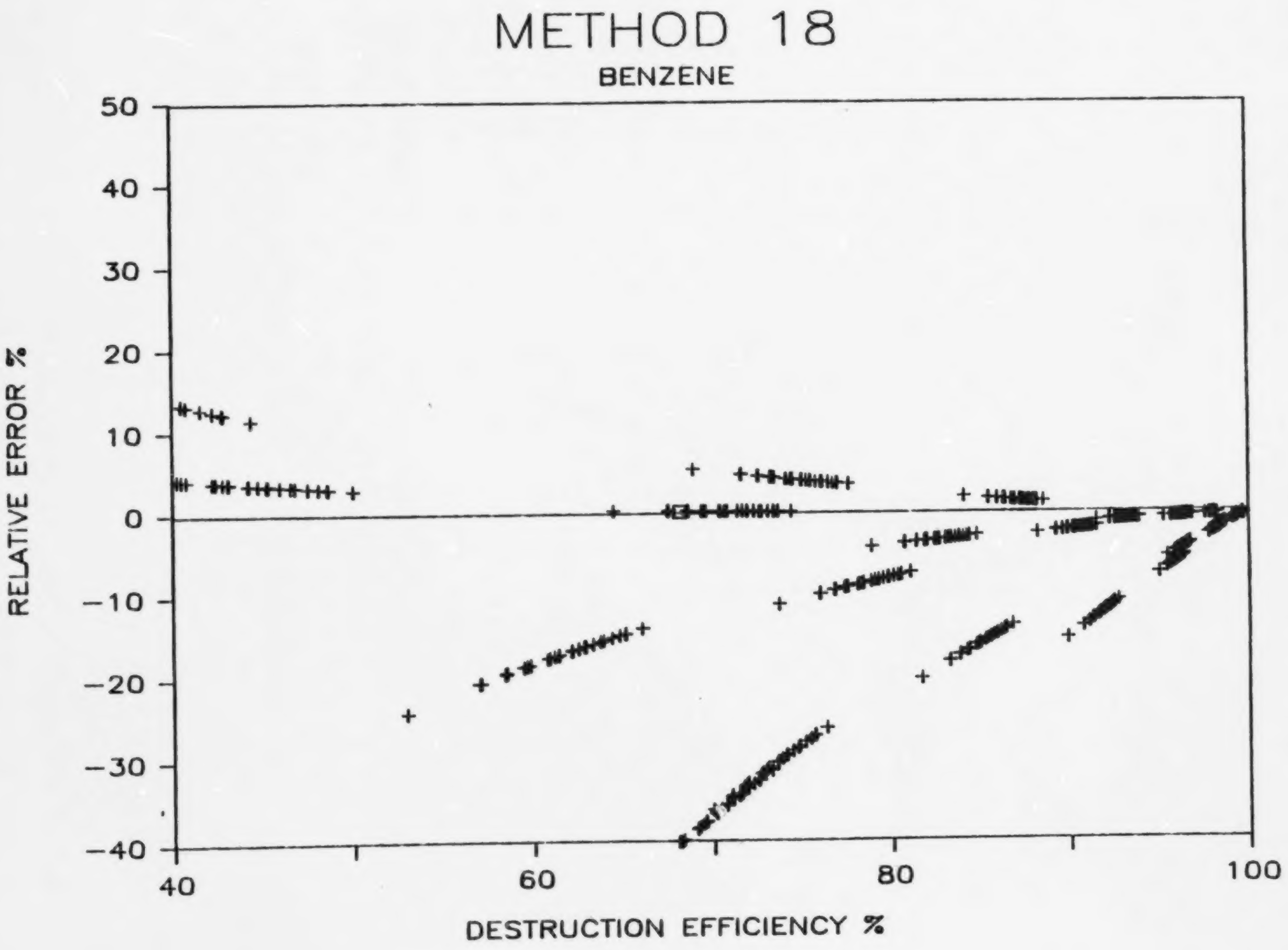

Figure A-1. Relative error as a function of destruction efficiency for benzene by Method 18.

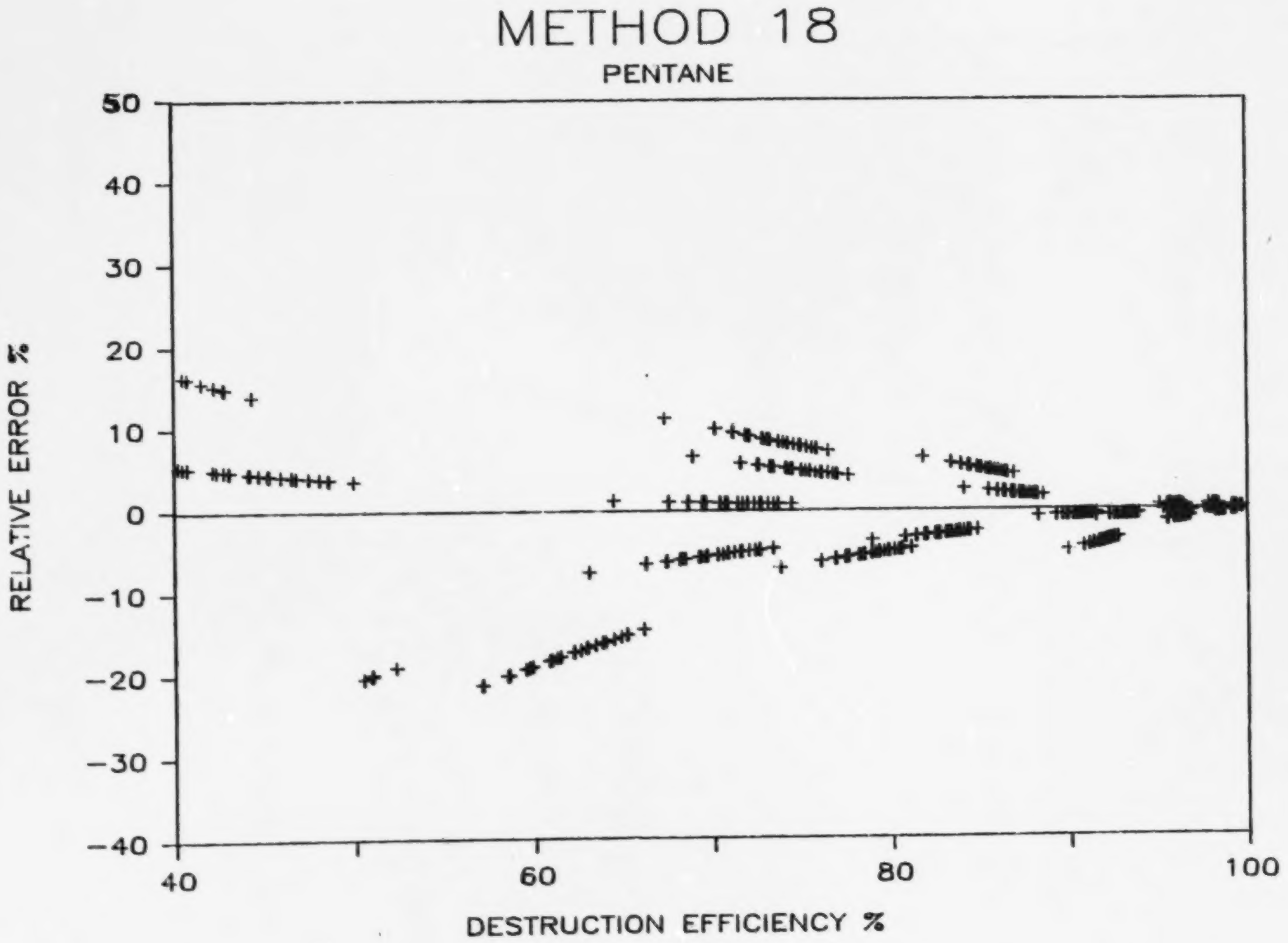

Figure A-2. Relative error as a function of destruction efficiency for pentane by Method 18.

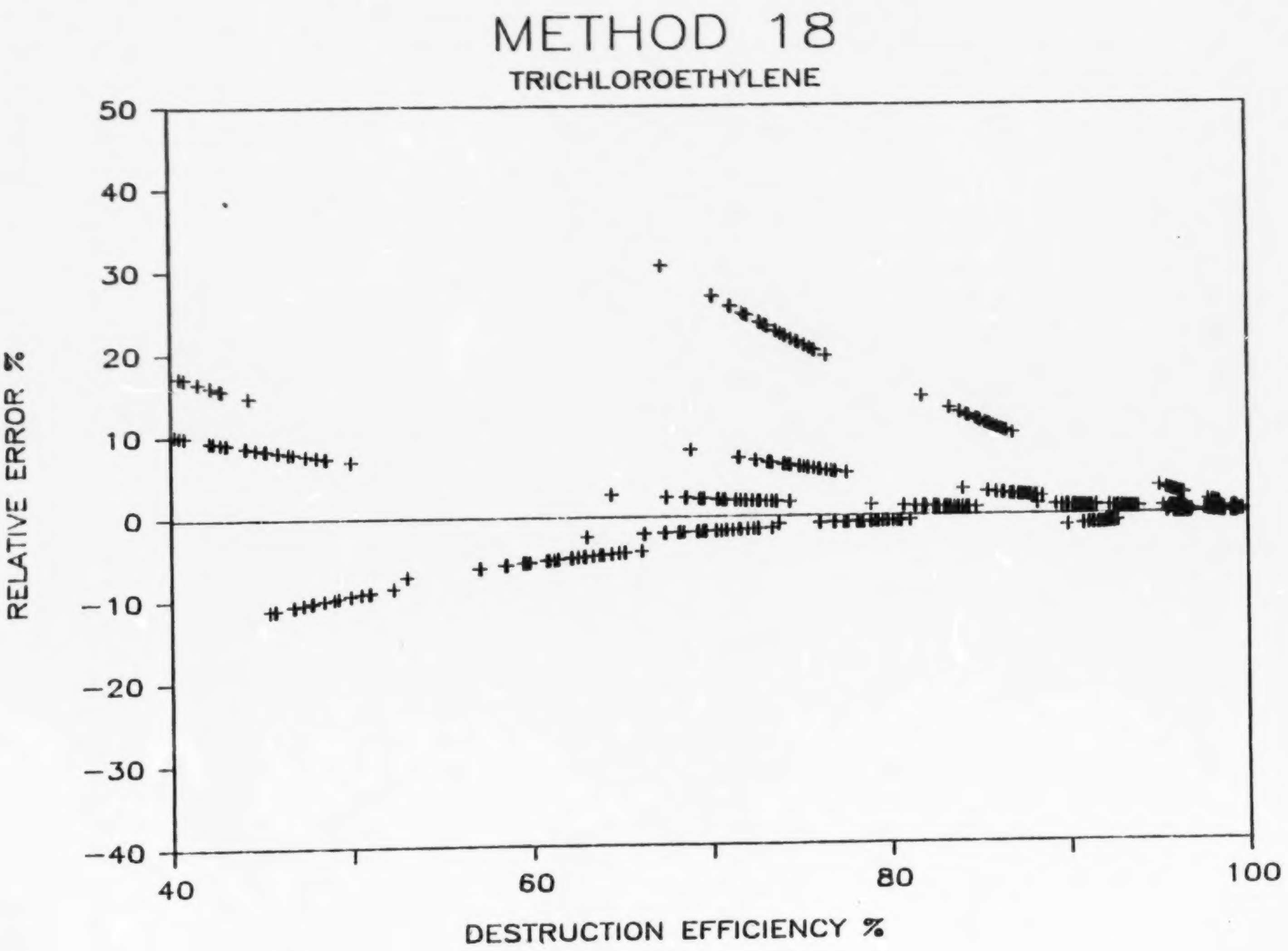

Figure A-3. Relative error as a function of destruction efficiency for trichloroethylene by Method 18.

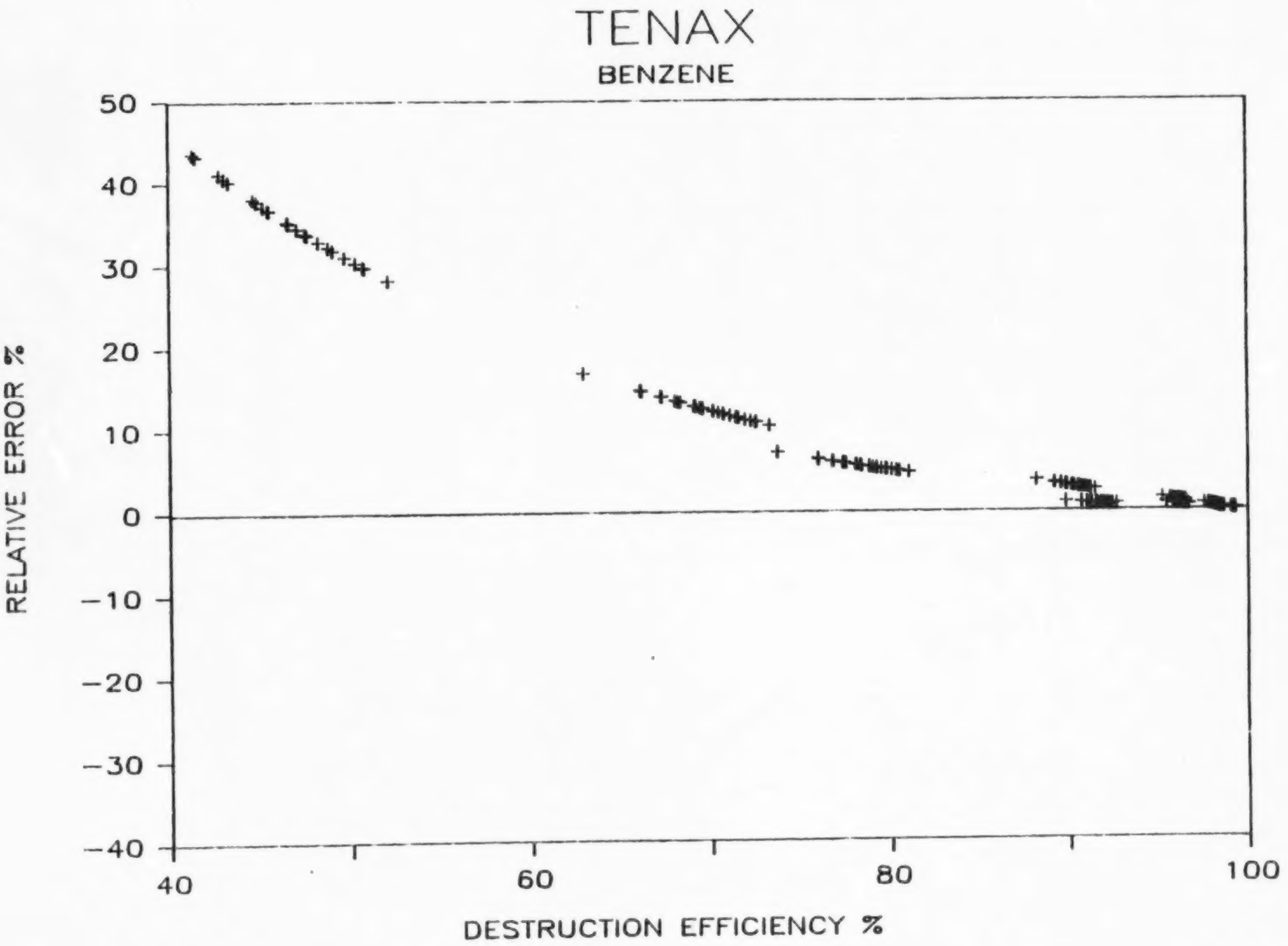

Figure A-4. Relative error as a function of destruction efficiency for benzene by Tenax method.

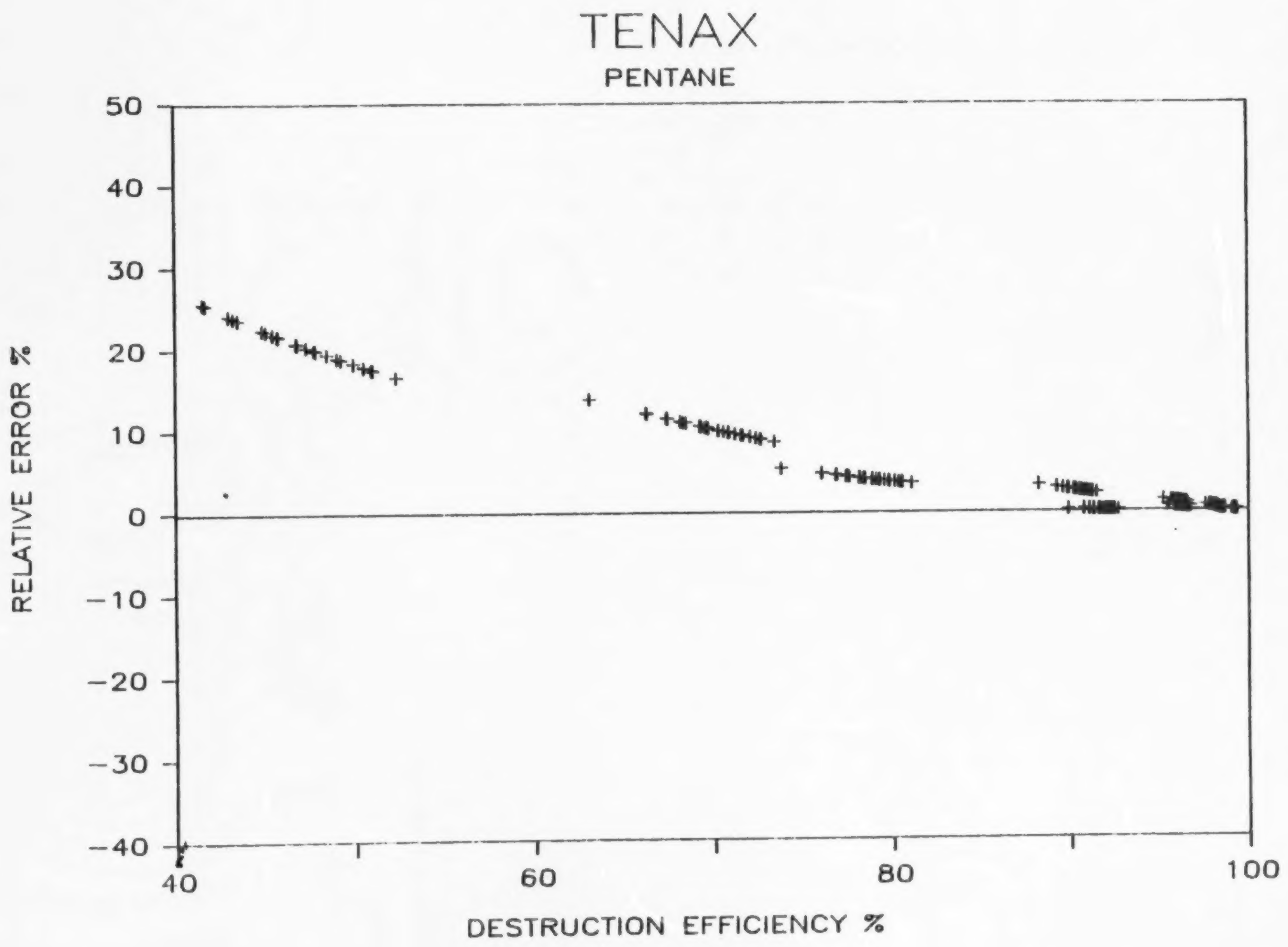

Figure A-5. Relative error as a function of destruction efficiency for pentane by Tenax method.

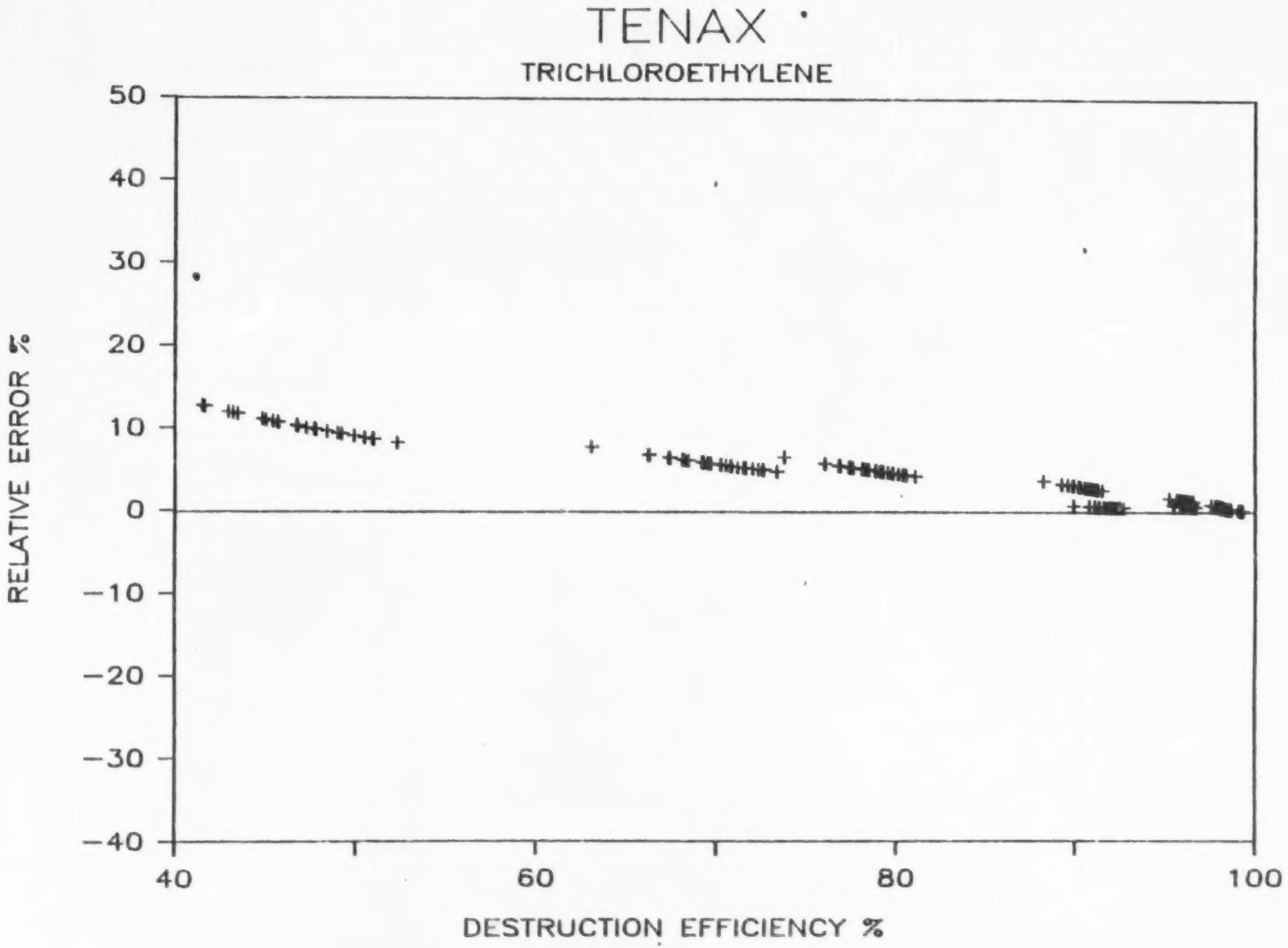

Figure A-6. Relative error as a function of destruction efficiency for trichloroethylene by Tenax method.

## TABLE A-7. UNCERTAINTY IN MEASURED DESTRUCTION EFFICIENCY FOR "ACTUAL" DESTRUCTION EFFICIENCIES >90%

| Method | Species | Number of Observations Generated | Median % Relative Error | 95% Bounds on Relative Error Estimates[a] | Percent Outside 10% Error Limits |
|---|---|---|---|---|---|
| 18 | Benzene | 355 | -0.93 | (-12.6,-0.36) | 7.6 |
| | Pentane | 355 | -0.19 | (-4.1,0.38) | 0.0 |
| | Trichloroethylene | 355 | 0.34 | (-1.1,2.7) | 0.0 |
| Tenax | Benzene | 187 | 0.66 | (0.13,3.0) | 0.0 |
| | Pentane | 187 | 0.49 | (0.11,2.6) | 0.0 |
| | Trichloroethylene | 187 | 0.63 | (0.15,3.0) | 0.0 |

[a] 95% of the generated relative error (% bias) estimates were within these limits.

### A.3.2 Carbon Monoxide Analyses

In addition to VOC measurements, the performance audit also addressed carbon monoxide (CO) measurements at the incinerator outlet. As for the VOC measurements, the audit consisted of challenging the instrument (Bendix Model 8501-5CA infrared analyzer) with multiple test atmospheres over the concentration range of interest. Five audit points were used over the range from 2 ppm to 60 ppm CO. The four lower concentrations were generated by dynamic dilution of a certified standard mixture containing 60 ppm CO.

Audit results for the CO analyzer are summarized in Table A-8. As indicated in the table, measured CO concentrations were within ±2 ppm of the input value at all audit points. The average error over the audit range was 1.3% of full scale. All points were easily within the performance objectives of error ≤5% of full scale. The instrument also showed good linearity over the audit range with a correlation coefficient of >0.999.

## A.4 QUALITY CONTROL DATA

Quality control efforts for this program focused on the use of quality control check standards to:

- verify acceptability of daily calibration,
- control and assess day-to-day variability, and
- control and assess instrument response drift.

Results of these QC checks are presented in this section.

### A.4.1 Method 18 QC Data

The quality control check standard for Method 18 was a certified gas mixture containing approximately 5 ppmv-C trichloroethylene in hydrocarbon-free air. Control standard analyses were conducted at two different times each day: after calibration and prior to testing (pretest), and at the

## TABLE A-8. CARBON MONOXIDE AUDIT RESULTS

| Input Concentration (ppm) | Instrument Response (ppm) | Error (ppm) | Percent of Full Scale[a] (%) |
|---|---|---|---|
| 2.16 | 1.5 | -0.66 | 1.3 |
| 10.8 | 9.5 | -1.3 | 2.5 |
| 20.0 | 19.5 | -0.5 | 0.9 |
| 32.0 | 32.5 | +0.5 | 1.0 |
| 60.5 | 58.8 | -1.7 | 0.7 |
|  | Mean | -0.7 | 1.3 |
|  | Standard Deviation | 0.8 |  |

Regression Parameters

Slope = 0.990
y-intercept = -0.48
Correlation Coefficient = 0.9993

---

[a] Measurement error expressed as a percentage of the full-scale value; QA objective was ≤5% of ful scale.

[b] Full scale for this point was 250 ppm; full scale at all other points was 50 ppm.

conclusion of the testing (posttest). The pretest check consisted of three analyses of the control standard, serving as a QC check of within-day variability (of individual measurements), as well as a check of calibration acceptability. The control limits for these replicate analyses were average agreement within ±10% of the certified concentration of the standard and variability among the replicate values ≤5% (in terms of the coefficient of variation). Comparison of average measured values over time also provides an estimate of day-to-day variability.

Two different control standard mixtures were used for Method 18 QC checks over the course of the project. Results for the first mixture are presented in Figure A-7 and results for the second are presented in Figure A-8. The different symbols represent results obtained during testing with the four different test mixtures which were used. Mixture 1 results are represented by the symbol "□," Mixture 2 by "+," Mixture 3 by "◇," and Mixture 4 by "Δ." As indicated in Figure A-8, all QC results for Mixture #4 were outside the ±10% acceptance window. Since variability in these data was no greater than observed for other results (i.e., results obtained during testing with the other mixtures), a discrepancy (approximately 20% high) in the calibration standard for Mixture 4 is suggested. It is not possible to determine from these QC data whether the certified concentrations of all components in this mixture were in error or if the problem affected only trichloroethylene results.

Excluding Mixture 4 results, all Method 18 QC checks except one (Mixture 3) met the ±10% acceptance criterion. Day-to-day variability (excluding Mixture 4 results) was less than 5%, as indicated by the CV for daily mean measured values for the QC check standards. Within-day variability was better than 2% based on the pooled CV results of triplicate analyses of the QC standard.

The posttest analyses of the QC check standard provide an estimate of within-day instrument drift. Method 18 drift check results are plotted in Figure A-9. The drift criterion of ≤5% drift was exceeded for approximately

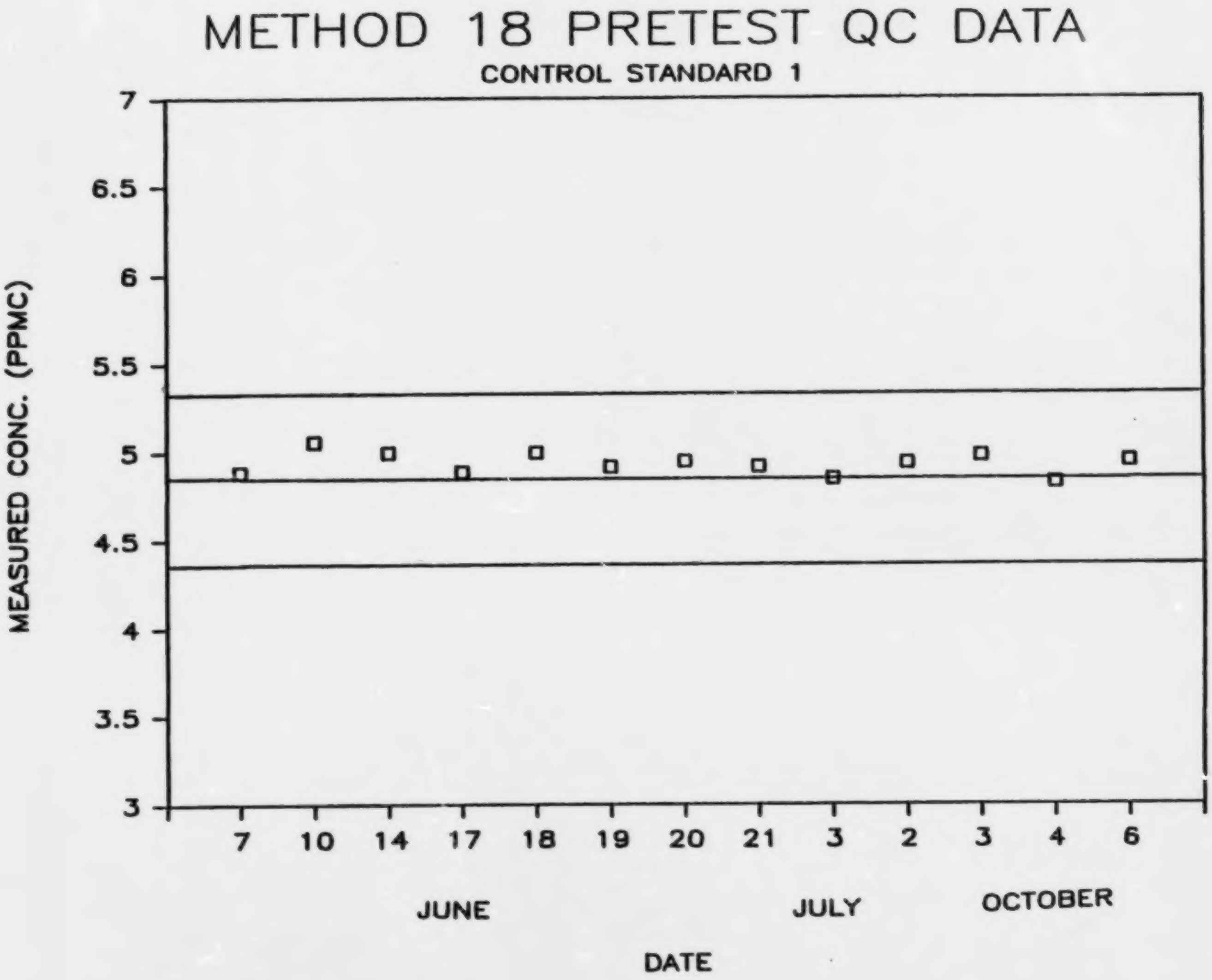

Figure A-7. Method 18 Pretest QC Data - Control Standard 1

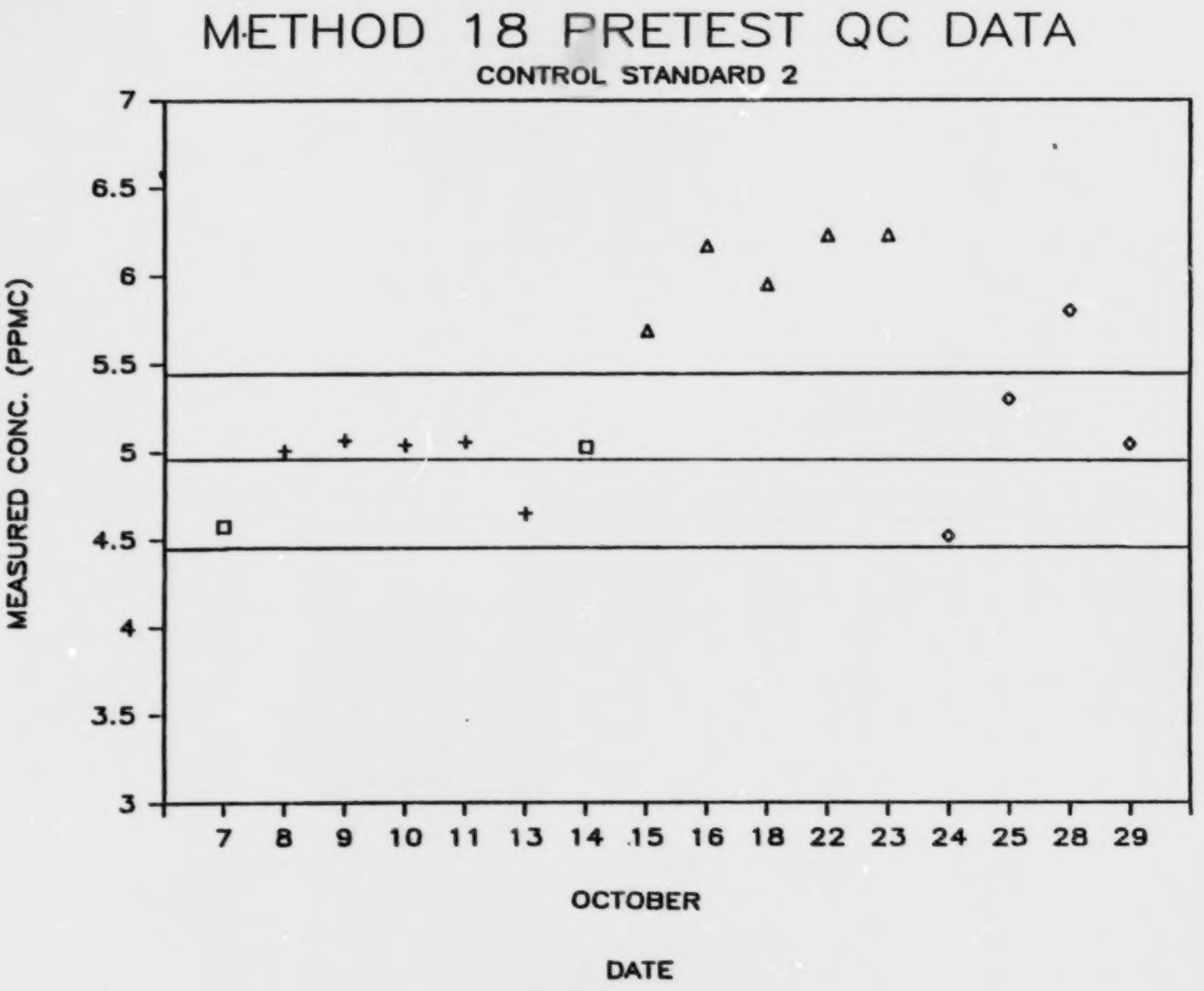

Figure A-8. Method 18 Pretest QC Data - Control Standard 2

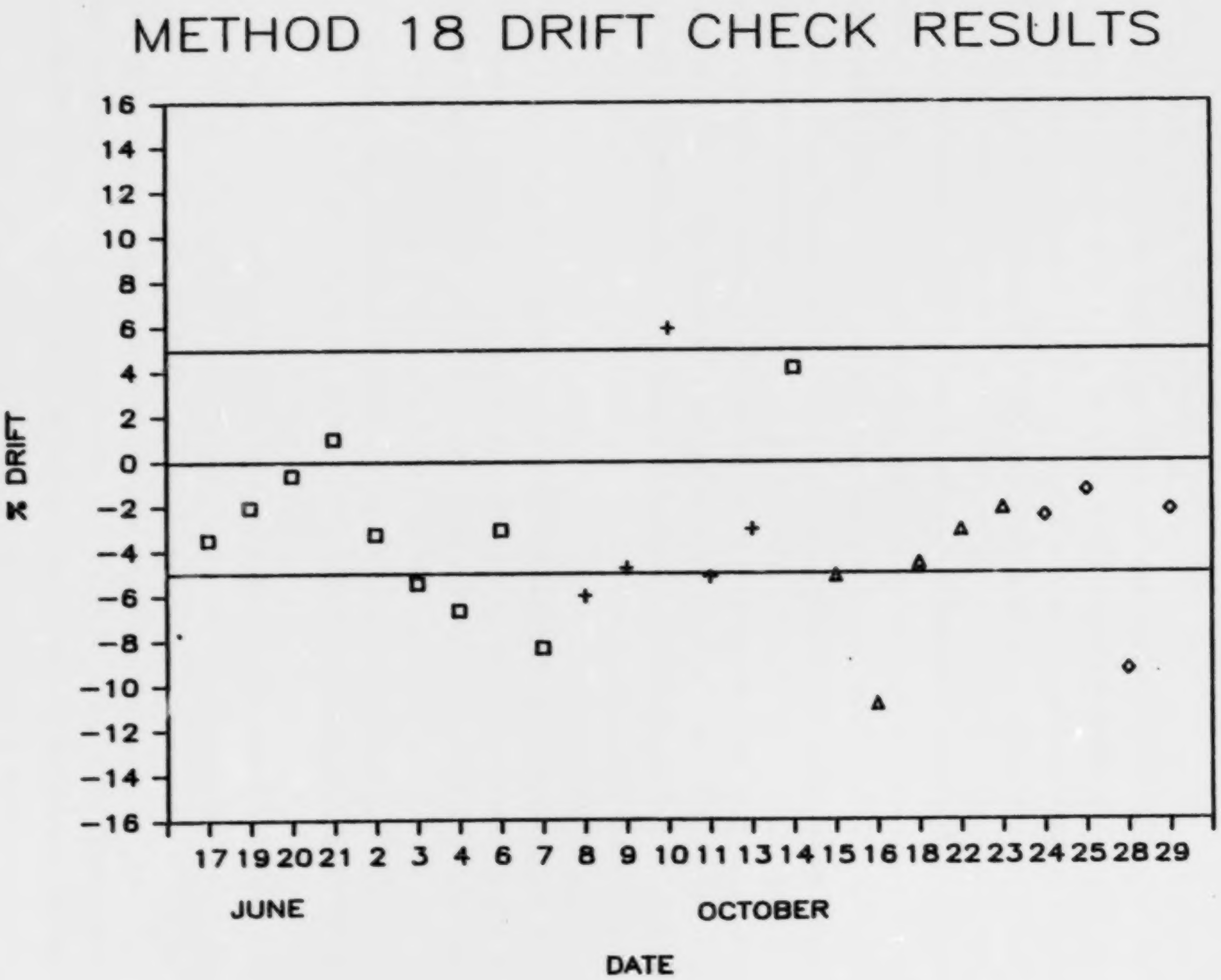

Figure A-9. Method 18 Drift Check Results

25% of the drift checks performed. In only one instance (October 16), however, did drift exceed ±10%.

### A.4.2 Tenax QC Data

Quality control checks for the Tenax resin analyses consisted of a daily pre- and posttest calibration check of the FID detectors against a QC check standard. Separate QC tests were performed for each column/detector combination (Side A and Side B) as dictated by what was to be used for that day's analyses. Specific acceptance criteria were not defined for these QC checks. Precision and bias objectives of 20% and ±15%, respectively, suggest comparable targets for QC standard recovery and percent drift. Pretest QC data for Tenax analyses are presented in Figure A-10. As indicated in this figure, relative recovery for the control standard generally ranged from about 75% to about 120% (i.e., ±25%), although occasional excursions ranged as high as 160% recovery. Day-to-day variability was approximately 25% for Side A and 17% for Side B, expressed in terms of the coefficients of variation for percent recovery for the pretest QC check. The pooled CV, representing overall variability for both sides, is 20%.

Posttest QC data for Tenax analyses are shown in Figure A-11. For Side B, drift ranged from -1% to over 60%, in terms of % recovery between pre- and posttest results. Average drift was about 30%. Only a single posttest QC check was performed for Side A, indicating approximately -12% drift.

### A.4.3 Carbon Monoxide QC Data

Quality control for carbon monoxide (CO) analyses consisted primarily of daily analyses of a carbon monoxide quality control check standard prior to and after testing. Data for these QC checks are plotted in Figures A-12 and A-13 for pre- and posttest results, respectively. The acceptance criterion for the initial QC check was agreement of the measured value within ±5% of the "actual" control standard concentration. Although 20% of the checks exceeded this criterion, all except one was within ±10% of the actual

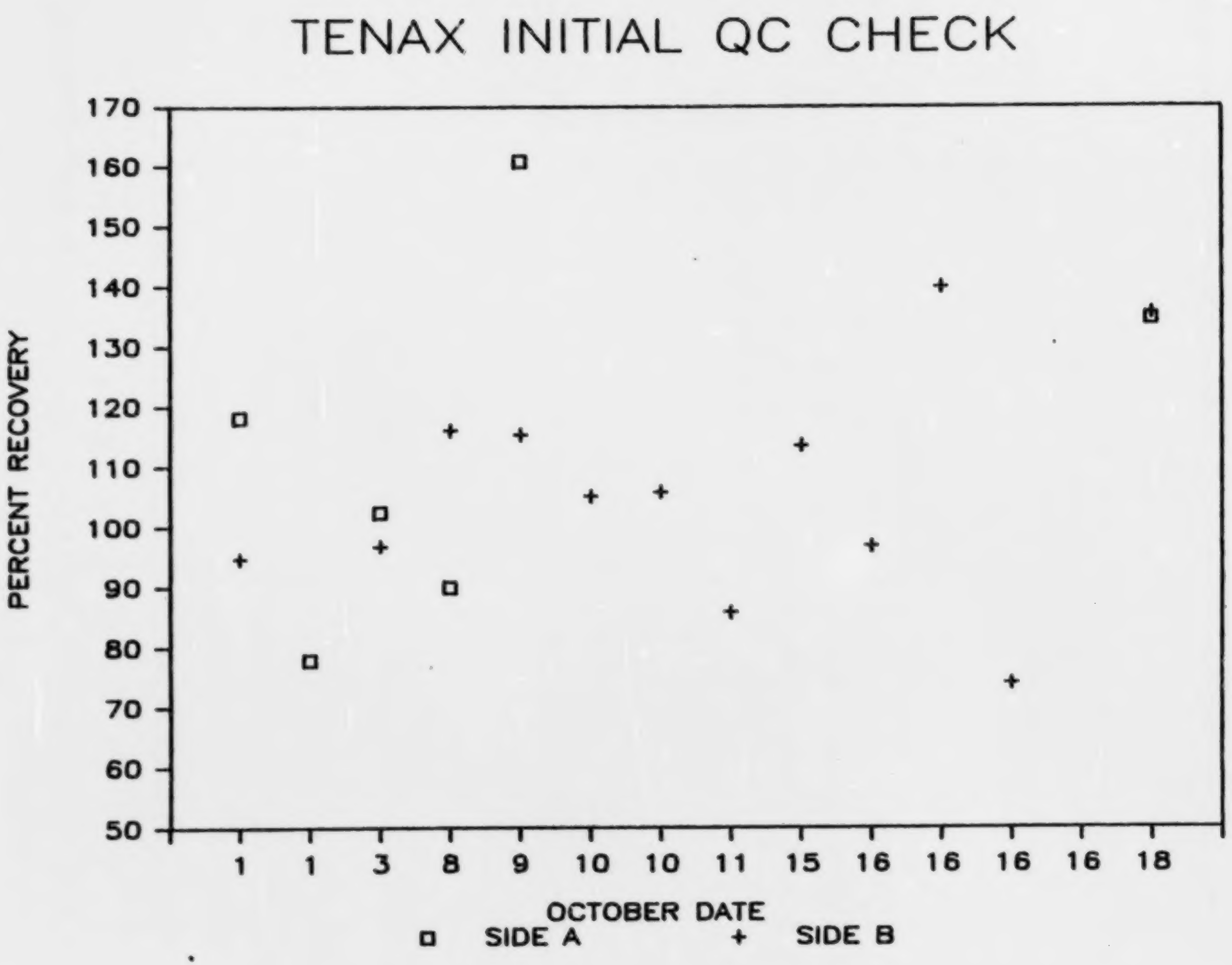

Figure A-10. Tenax Initial QC Check

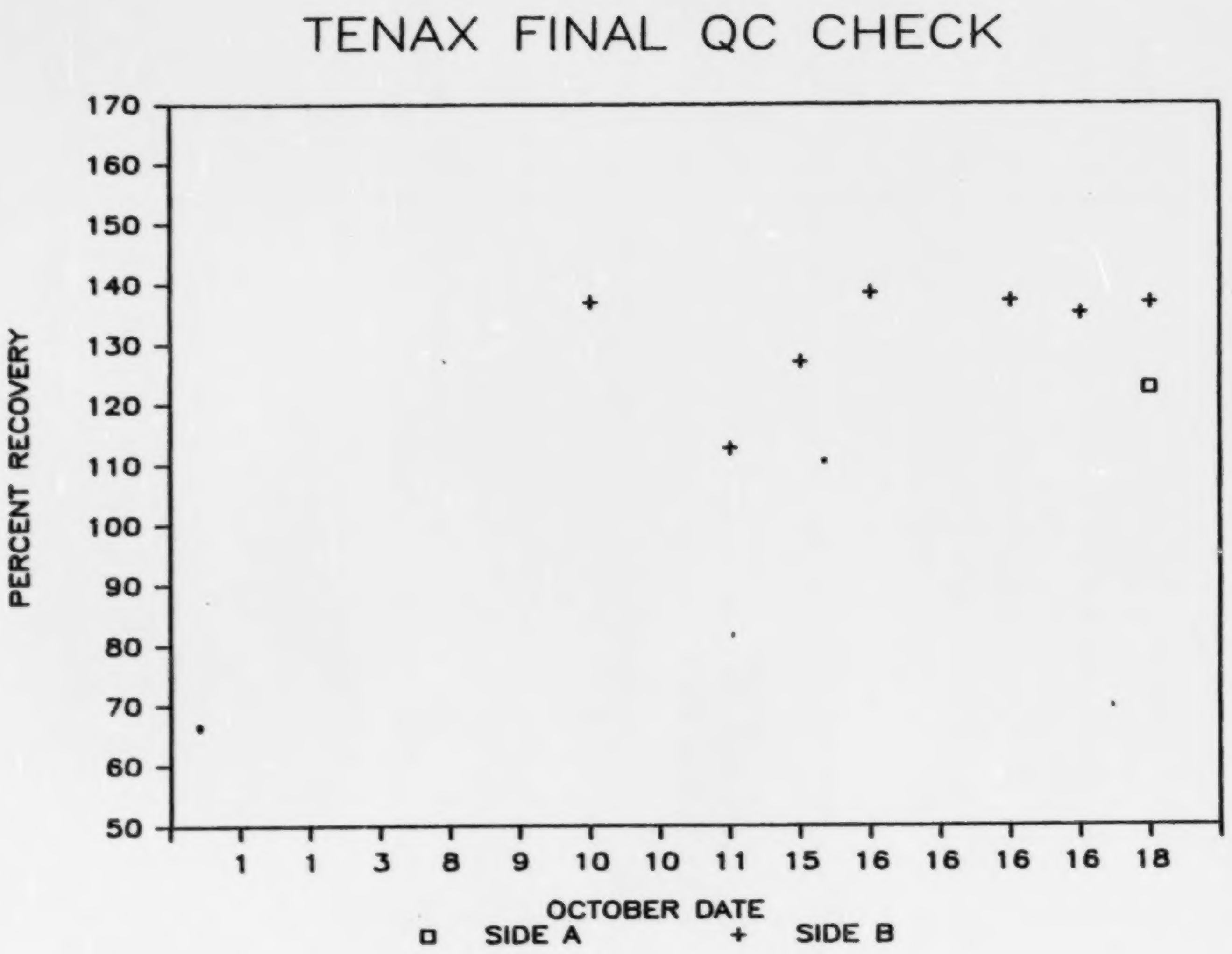

Figure A-11. Tenax Final QC Check

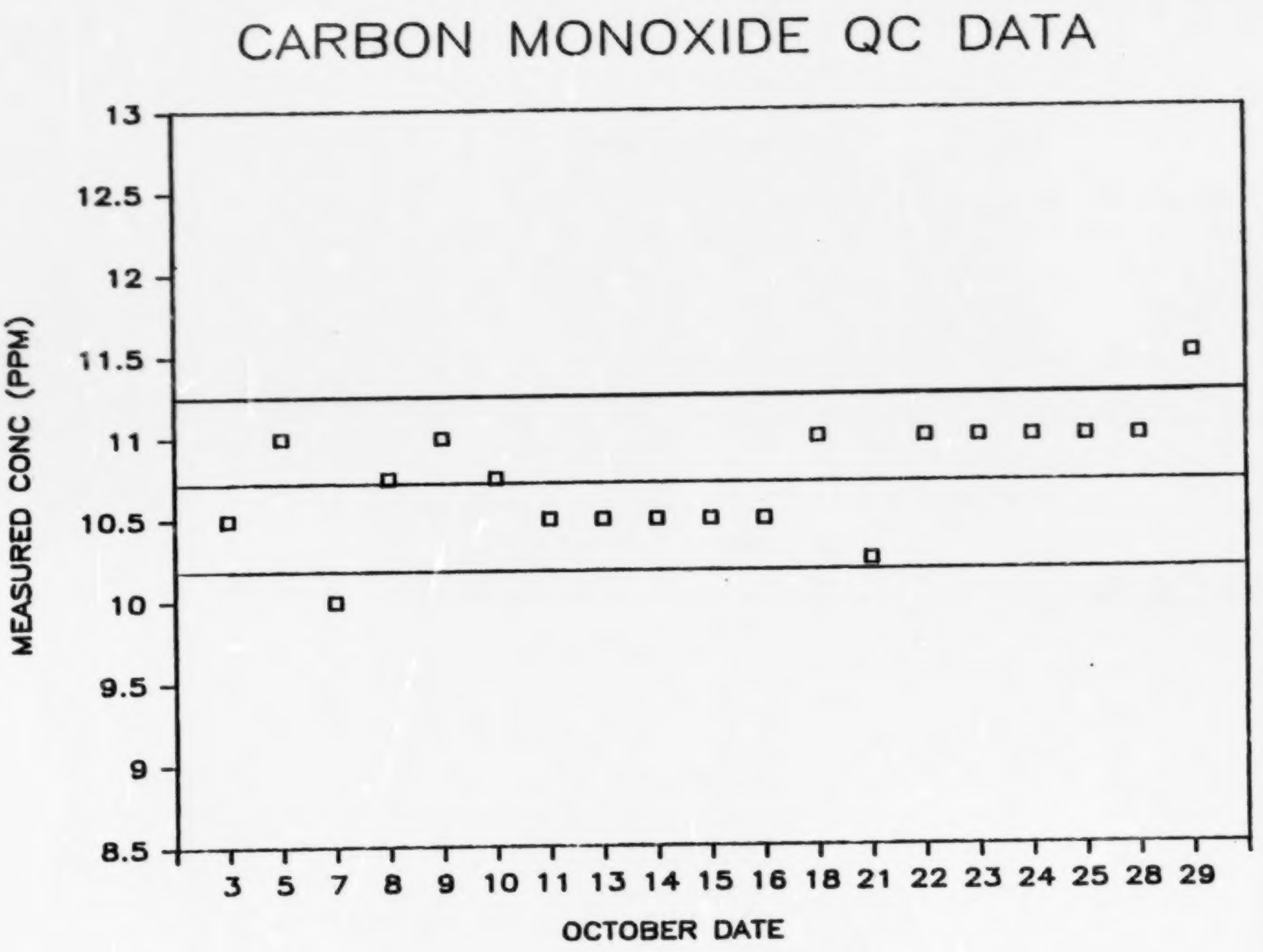

Figure A-12. Carbon Monoxide QC Data

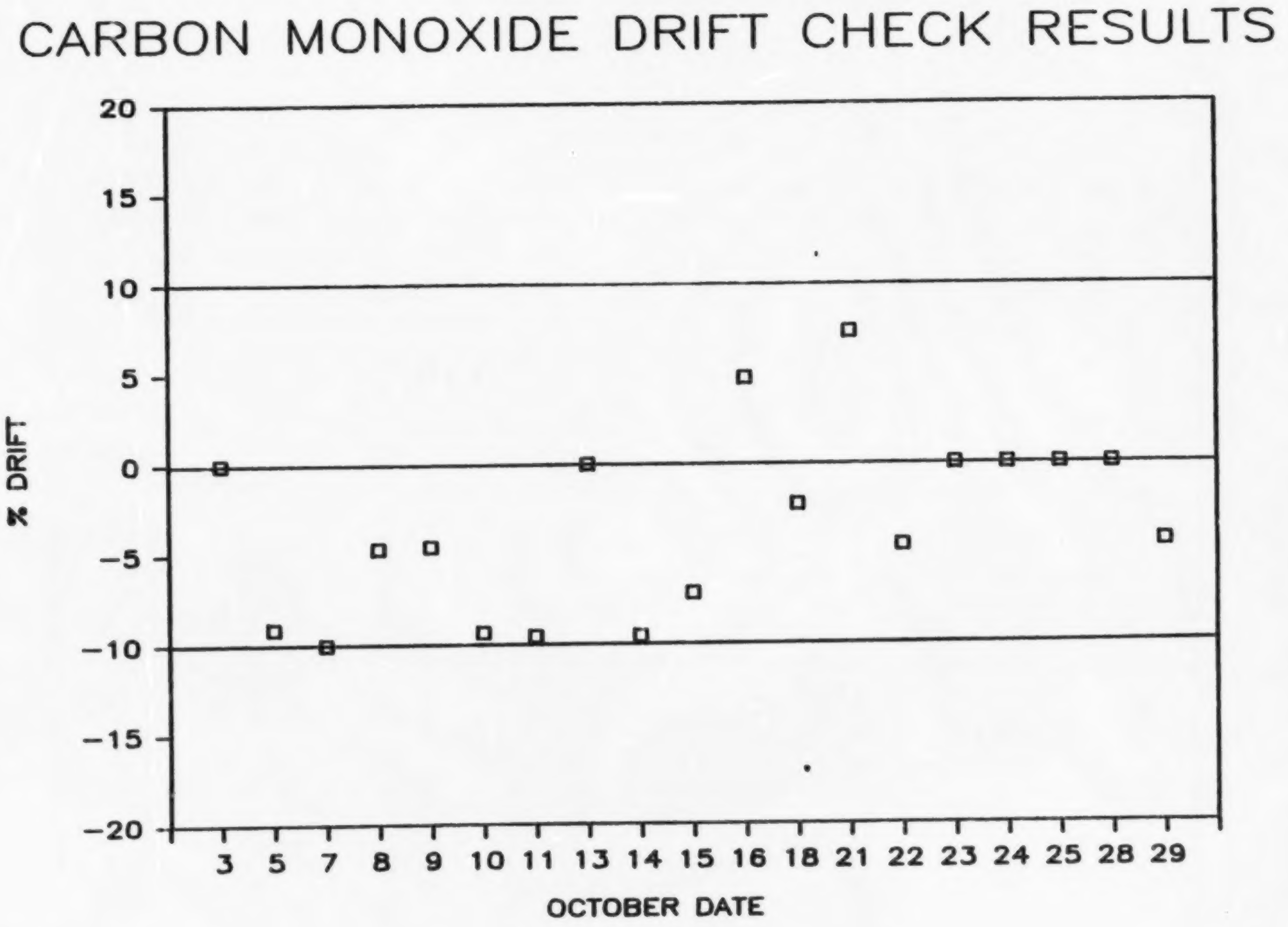
CARBON MONOXIDE DRIFT CHECK RESULTS

Figure A-13. Carbon Monoxide Drift Check Results concentration. For the 10.72 ppm control standard used, a 5% error represented only 0.53 ppm. Day-to-day variability for the control standard analyses was about 3.5%, expressed as the coefficient of variation.

At the conclusion of each day's testing, the control standard was analyzed again to determine within-day response drift. For this check, the relative difference between the pretest and posttest responses was to be within ±5%. The 5% drift objective was exceeded about one-third of the time, but all drift check results fell within ±10% drift.

# APPENDIX B

## UNIT CONVERSIONS

| To Convert From English | To SI | Multiply By |
|---|---|---|
| cfm | $m^3/hr$ | 1.70 |
| ft | m | 0.305 |
| in. | m | 0.0254 |
| in. $H_2O$ | Pa | 249 |
| psi | Pa | 6893 |
| lb | kg | 0.454 |
| gal | $m^3$ | $3.79 \times 10^{-3}$ |
| BTU | kJ | 1.055 |

The temperature conversion formula between English and SI Units is:

$$\frac{°F - 32}{9} = \frac{°C}{5} \qquad \text{(B-1)}$$

Where: °F = degrees Fahrenheit

°C = degrees Celsius

# APPENDIX C

## METHOD 18 AND TENAX-GC DATA FOR FLUIDIZED BED INCINERATOR

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-1 | SPACE VELOCITY (#/HR) | 10300 | COMBUSTION AIR RATE (SCFM) | 173 |
| MIXTURE | 1 | CATALYST INLET TEMP (DEG F) | 701 | NATURAL GAS USAGE (SCFM) | 8.02 |
| DATE | 10/02/85 | CATALYST OUTLET TEMP (DEG F) | 683 | AIR TO GAS RATIO (SCF/SCF) | 22:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 75 | CATALYST PRESS DROP (INCHES H20) | 11.7 |
| | | INLET GAS FLOW RATE (SCFM) | 487 | OUTLET CARBON MONOXIDE (PPMV) | 78 |
| | | OUTLET GAS FLOW RATE (SCFM) | 660 | MOISTURE CORRECTION FACTOR | 0.952 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHYLENE | 7.53 | 3.68 | 0.77 | | 86 | 1.80 | (81.5, 90.5) | 79 | 3.19 | (71.1, 86.9) |
| TRICHLOROETHYLENE | 5.26 | 2.74 | 0.40 | | 90 | 1.80 | (85.5, 94.5) | 85 | 3.19 | (77.1, 92.9) |
| TOTAL: | 12.79 | 6.41 | 1.17 | | 88 | 1.80 | (83.5, 92.5) | 82 | 3.19 | (74.1, 89.9) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHYLENE | 34 | 6.81 | (17.1, 50.9) | | | | | | |
| TRICHLOROETHYLENE | 30 | 6.81 | (13.1, 46.9) | | | | | | |
| TOTAL: | 32 | 6.81 | (15.1, 48.9) | | | | | | |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-2 | SPACE VELOCITY (#/HR) | 6800 | COMBUSTION AIR RATE (SCFM) | 231 |
| MIXTURE | 1 | CATALYST INLET TEMP (DEG F) | 709 | NATURAL GAS USAGE (SCFM) | 6.74 |
| DATE | 10/03/85 | CATALYST OUTLET TEMP (DEG F) | 687 | AIR TO GAS RATIO (SCF/SCF) | 34:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 82 | CATALYST PRESS DROP (INCHES H2O) | 10.1 |
|  |  | INLET GAS FLOW RATE (SCFM) | 323 | OUTLET CARBON MONOXIDE (PPMV) | 32 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 554 | MOISTURE CORRECTION FACTOR | 0.955 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | STD. | 95% C.I. |  | STD. | 95% C.I. |
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1,2 - DICHLOROETHYLENE | 10.15 | 4.98 | 0.69 | 0.48 | 88 | 1.80 | (86.5, 89.5) | 86 | 3.19 | (80.9, 91.1) |
| TRICHLOROETHYLENE | 7.60 | 3.97 | 0.29 | 0.42 | 93 | 1.80 | (91.5, 94.5) | 93 | 3.19 | (87.9, 98.1) |
| TOTAL: | 17.74 | 8.95 | 0.98 | 0.89 | 91 | 1.80 | (89.5, 92.5) | 89 | 3.19 | (83.9, 94.1) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | STD. | 95% C.I. |  | STD. | 95% C.I. |  | STD. | 95% C.I. |
| SPECIES | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1,2 - DICHLOROETHYLENE | 16 | 6.81 | (10.3, 21.7) | 92 | 1.80 | (90.5, 93.5) | 91 | 3.19 | (85.9, 96.1) |
| TRICHLOROETHYLENE | 10 | 6.81 | ( 2.8, 17.2) | 91 | 1.80 | (89.1, 92.9) | 90 | 3.19 | (84.9, 95.1) |
| TOTAL: | 14 | 6.81 | ( 7.7, 20.3) | 92 | 1.80 | (90.3, 93.7) | 90 | 3.19 | (84.9, 95.1) |

```
RUN #        B-3  SPACE VELOCITY (#/HR)         10300      COMBUSTION AIR RATE (SCFM)             174
MIXTURE        1  CATALYST INLET TEMP (DEG F)     648      NATURAL GAS USAGE (SCFM)              7.30
DATE    10/04/85  CATALYST OUTLET TEMP (DEG F)    633      AIR TO GAS RATIO (SCF/SCF)            24:1
                  INCINERATOR INLET TEMP (DEG F)   80      CATALYST PRESS DROP (INCHES H2O)      11.7
                  INLET GAS FLOW RATE (SCFM)      488      OUTLET CARBON MONOXIDE (PPMV)           61
                  OUTLET GAS FLOW RATE (SCFM)     662      MOISTURE CORRECTION FACTOR           0.000


                                                           :SYSTEM DESTRUCTION GC/FID (%):CATALYST DESTRUCTION GC/FID (%)
                           AVERAGE CONCENTRATION (PPMV)    :        STD.     95% C.I.    :        STD.      95% C.I.     :
 SPECIES                 INLET  PREHEATER  GC OUTLET TENAX OUTLET: MEAN  DEV.  ON THE MEAN  :  MEAN  DEV.    ON THE MEAN   :
                           *                               :                             :                               :
1,2 - DICHLOROETHYLENE   7.64    3.73       0.83           :  85    1.80  (82.8,  87.2)  :  78    3.19    (70.1,  85.9)  :
TRICHLOROETHYLENE        5.42    2.70       0.56           :  86    1.80  (83.8,  88.2)  :  79    3.19    (71.1,  86.9)  :
                                                           :                             :                               :
TOTAL:                  13.06    6.43       1.39           :  86    1.80  (83.8,  88.2)  :  78    3.19    (70.1,  85.9)  :


                         HEATER DESTRUCTION GC/FID (%) :    SYSTEM DESTRUCTION TENAX (%)    :  CATALYST DESTRUCTION TENAX (%)  :
                              STD.      95% C.I.       :          STD.        95% C.I.      :          STD.     95% C.I.       :
 SPECIES                 MEAN DEV.    ON THE MEAN      :   MEAN   DEV.      ON THE MEAN     :  MEAN    DEV.   ON THE MEAN     :
                                                       :                                    :                                  :
1,2 - DICHLOROETHYLENE    34  6.81   (17.1,  50.9)     :                                    :                                  :
TRICHLOROETHYLENE         33  6.81   (16.1,  49.9)     :                                    :                                  :
                                                       :                                    :                                  :
TOTAL:                    33  6.81   (16.1,  49.9)     :                                    :                                  :
```

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-4 | SPACE VELOCITY (#/HR) | 10100 | COMBUSTION AIR RATE (SCFM) | 196 |
| MIXTURE | 1 | CATALYST INLET TEMP (DEG F) | 792 | NATURAL GAS USAGE (SCFM) | 9.44 |
| DATE | 10/06/85 | CATALYST OUTLET TEMP (DEG F) | 768 | AIR TO GAS RATIO (SCF/SCF) | 21:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 73 | CATALYST PRESS DROP (INCHES H2O) | 12.2 |
| | | INLET GAS FLOW RATE (SCFM) | 480 | OUTLET CARBON MONOXIDE (PPMV) | 42 |
| | | OUTLET GAS FLOW RATE (SCFM) | 676 | MOISTURE CORRECTION FACTOR | 0.000 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | STD. | 95% C.I. | | STD. | 95% C.I. |
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1,2 - DICHLOROETHYLENE | 10.1 | 3.88 | 0.57 | | 92 | 1.80 | (89.8, 94.2) | 85 | 3.19 | (77.1, 92.9) |
| TRICHLOROETHYLENE | 6.60 | 2.78 | 0.31 | | 93 | 1.80 | (90.8, 95.2) | 89 | 3.19 | (81.1, 96.9) |
| TOTAL: | 16.7 | 6.67 | 0.87 | | 93 | 1.80 | (90.8, 95.2) | 87 | 3.19 | (79.1, 94.9) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | STD. | 95% C.I. | | STD. | 95% C.I. | | STD. | 95% C.I. |
| SPECIES | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1,2 - DICHLOROETHYLENE | 46 | 6.81 | (37.5, 54.5) | | | | | | |
| TRICHLOROETHYLENE | 41 | 6.81 | (32.5, 49.5) | | | | | | |
| TOTAL: | 44 | 6.81 | (35.5, 52.5) | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RUN # | B-5 | SPACE VELOCITY (#/HR) | 6840 | COMBUSTION AIR RATE (SCFM) | 184 |
| MIXTURE | 1 | CATALYST INLET TEMP (DEG F) | 794 | NATURAL GAS USAGE (SCFM) | 7.20 |
| DATE | 10/06/85 | CATALYST OUTLET TEMP (DEG F) | 764 | AIR TO GAS RATIO (SCF/SCF) | 26:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 66 | CATALYST PRESS DROP (INCHES H2O) | 15.0 |
| | | INLET GAS FLOW RATE (SCFM) | 325 | OUTLET CARBON MONOXIDE (PPMV) | 19 |
| | | OUTLET GAS FLOW RATE (SCFM) | 509 | MOISTURE CORRECTION FACTOR | 0.950 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | STD. | 95% C.I. | | STD. | 95% C.I. |
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1.2 - DICHLOROETHYLENE | 11.6 | 5.38 | 0.48 | | 94 | 1.80 | (91.8, 96.2) | 91 | 3.19 | (83.1, 98.9) |
| TRICHLOROETHYLENE | 7.60 | 3.51 | 0.17 | | 97 | 0.44 | (96.4, 97.6) | 95 | 0.44 | (93.9, 96.1) |
| TOTAL: | 19.2 | 8.89 | 0.64 | | 95 | 0.44 | (92.8, 97.2) | 93 | 3.19 | (85.1, 100.0) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | STD. | 95% C.I. | | STD. | 95% C.I. | | STD. | 95% C.I. |
| SPECIES | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1.2 - DICHLOROETHYLENE | 27 | 6.81 | (10.1, 43.9) | | | | | | |
| TRICHLOROETHYLENE | 28 | 6.81 | (11.1, 44.9) | | | | | | |
| TOTAL: | 28 | 6.81 | (11.1, 44.9) | | | | | | |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-6 | SPACE VELOCITY (#/HR) | 6720 | COMBUSTION AIR RATE (SCFM) | 136 |
| MIXTURE | 1 | CATALYST INLET TEMP (DEG F) | 943 | NATURAL GAS USAGE (SCFM) | 7.69 |
| DATE | 10/07/85 | CATALYST OUTLET TEMP (DEG F) | 901 | AIR TO GAS RATIO (SCF/SCF) | 18:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 73 | CATALYST PRESS DROP (INCHES H2O) | 10.3 |
|  |  | INLET GAS FLOW RATE (SCFM) | 319 | OUTLET CARBON MONOXIDE (PPMV) | 2 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 455 | MOISTURE CORRECTION FACTOR | 0.958 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1.2 - DICHLOROETHYLENE | 10.9 | 3.26 | 0.23 | 0.06 | 97 | 0.44 | (96.7, 97.3) | 93 | 3.19 | (85.1, 100.0) |
| TRICHLOROETHYLENE | 6.90 | 2.41 | 0.06 | 0.04 | 99 | 0.44 | (98.7, 99.3) | 98 | 0.44 | (96.9, 99.1) |
| TOTAL: | 17.8 | 5.67 | 0.29 | 0.10 | 98 | 0.44 | (97.7, 98.3) | 95 | 0.44 | (87.1, 100.0) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHYLENE | 56 | 6.81 | (51.8, 62.2) | 99 | 0.44 | (98.7, 99.3) | 98 | 0.44 | (96.9, 99.1) |
| TRICHLOROETHYLENE | 50 | 6.81 | (44.8, 55.2) | 99 | 0.44 | (98.7, 99.3) | 99 | 0.44 | (97.9, 100.0) |
| TOTAL: | 55 | 6.81 | (49.8, 60.2) | 99 | 0.44 | (98.7, 99.3) | 98 | 0.44 | (96.9, 99.1) |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-7 | SPACE VELOCITY (#/HR) | 9810 | COMBUSTION AIR RATE (SCFM) | 178 |
| MIXTURE | 1 | CATALYST INLET TEMP (DEG F) | 943 | NATURAL GAS USAGE (SCFM) | 11.0 |
| DATE | 10/07/85 | CATALYST OUTLET TEMP (DEG F) | 915 | AIR TO GAS RATIO (SCF/SCF) | 16:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 65 | CATALYST PRESS DROP (INCHES H2O) | 12.4 |
| | | INLET GAS FLOW RATE (SCFM) | 466 | OUTLET CARBON MONOXIDE (PPMV) | 20 |
| | | OUTLET GAS FLOW RATE (SCFM) | 644 | MOISTURE CORRECTION FACTOR | 0.958 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1.2 - DICHLOROETHYLENE | 10.2 | 3.33 | 0.21 | 0.10 | 97 | 0.44 | (96.4, 97.6) | 94 | 3.19 | (86.1, 100.0) |
| TRICHLOROETHYLENE | 7.11 | 2.49 | 0.08 | 0.07 | 99 | 0.44 | (98.4, 99.6) | 97 | 0.44 | (95.9, 98.1) |
| TOTAL: | 17.3 | 5.82 | 0.28 | 0.16 | 98 | 0.44 | (97.4, 98.6) | 95 | 0.44 | (93.9, 96.1) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1.2 - DICHLOROETHYLENE | 55 | 6.81 | (44.2, 65.8) | 99 | 0.44 | (98.4, 99.6) | 97 | 0.44 | (95.9, 98.1) |
| TRICHLOROETHYLENE | 52 | 6.81 | (43.5, 60.5) | 99 | 0.44 | (98.4, 99.6) | 97 | 0.44 | (95.9, 98.1) |
| TOTAL: | 53 | 6.81 | (44.5, 61.5) | 99 | 0.44 | (98.4, 99.6) | 97 | 0.44 | (95.9, 98.1) |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-8 | SPACE VELOCITY (#/HR) | 10500 | COMBUSTION AIR RATE (SCFM) | 150 |
| MIXTURE | 2 | CATALYST INLET TEMP (DEG F) | 807 | NATURAL GAS USAGE (SCFM) | 9.29 |
| DATE | 10/08/85 | CATALYST OUTLET TEMP (DEG F) | 788 | AIR TO GAS RATIO (SCF/SCF) | 16:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 71 | CATALYST PRESS DROP (INCHES H2O) | 11.9 |
|  |  | INLET GAS FLOW RATE (SCFM) | 500 | OUTLET CARBON MONOXIDE (PPMV) | 75 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 650 | MOISTURE CORRECTION FACTOR | 0.956 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 12.8 | 4.15 | 0.11 |  | 99 | 0.44 | (98.3. 99.7) | 97 | 0.44 | (95.9. 98.1) |
| CYCLOHEXANE | 15.2 | 3.93 | 0.08 |  | 99 | 0.44 | (98.3, 99.7) | 98 | 0.44 | (96.9. 99.1) |
| TRICHLOROETHYLENE | 2.95 | 1.54 | 0.10 |  | 96 | 0.44 | (95.3, 96.7) | 94 | 3.19 | (86.1, 100.0) |
| BENZENE | 1.95 | 1.56 | 0.16 |  | 90 | 1.80 | (89.3, 90.7) | 90 | 3.19 | (82.1, 97.9) |
| ETHYL BENZENE | 7.96 | 2.74 | 0.06 |  | 99 | 0.44 | (98.3, 99.7) | 98 | 0.44 | (96.9. 99.1) |
| TOTAL: | 40.8 | 13.92 | 0.49 |  | 98 | 0.44 | (97.3, 98.7) | 96 | 0.44 | (94.9, 97.1) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 57 | 6.81 | (47.2. 68.8) |  |  |  |  |  |  |
| CYCLOHEXANE | 66 | 6.81 | (55.2, 76.8) |  |  |  |  |  |  |
| TRICHLOROETHYLENE | 32 | 6.81 | (21.2, 42.8) |  |  |  |  |  |  |
| BENZENE | 0 |  |  |  |  |  |  |  |  |
| ETHYL BENZENE | 55 | 6.81 | (38.1, 71.9) |  |  |  |  |  |  |
| TOTAL: | 56 | 6.81 | (45.2. 66.8) |  |  |  |  |  |  |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-9 | SPACE VELOCITY (#/HR) | 7790 | COMBUSTION AIR RATE (SCFM) | 154 |
| MIXTURE | 2 | CATALYST INLET TEMP (DEG F) | 653 | NATURAL GAS USAGE (SCFM) | 5.84 |
| DATE | 10/09/85 | CATALYST OUTLET TEMP (DEG F) | 640 | AIR TO GAS RATIO (SCF/SCF) | 26:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 79 | CATALYST PRESS DROP (INCHES H2O) | 9.4 |
| | | INLET GAS FLOW RATE (SCFM) | 370 | OUTLET CARBON MONOXIDE (PPMV) | 75 |
| | | OUTLET GAS FLOW RATE (SCFM) | 524 | MOISTURE CORRECTION FACTOR | 0.954 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 11.0 | 3.77 | 0.21 | 0.24 | 97 | 0.44 | (96.6, 97.4) | 95 | 3.19 | (87.1, 100.0) |
| CYCLOHEXANE | 12.4 | 3.38 | 0.15 | 0.10 | 98 | 0.44 | (97.6, 98.4) | 96 | 0.44 | (94.9, 97.1) |
| TRICHLOROETHYLENE | 2.44 | 1.50 | 0.21 | 0.33 | 88 | 1.80 | (86.3, 89.7) | 86 | 3.19 | (78.1, 93.9) |
| BENZENE | 1.59 | 1.36 | 0.33 | 0.47 | 71 | 1.80 | (66.5, 75.5) | 76 | 3.19 | (68.1, 83.9) |
| ETHYL BENZENE | 5.81 | 2.73 | 0.07 | 0.08 | 98 | 0.44 | (97.5, 98.5) | 97 | 0.44 | (95.9, 98.1) |
| TOTAL: | 33.3 | 12.74 | 0.96 | 1.22 | 96 | 0.44 | (95.5, 96.5) | 93 | 3.19 | (85.1, 100.0) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 51 | 6.81 | (40.2, 61.8) | 97 | 0.44 | (96.6, 97.4) | 94 | 3.19 | (86.1, 100.0) |
| CYCLOHEXANE | 62 | 6.81 | (45.1, 78.9) | 99 | 0.44 | (98.6, 99.4) | 97 | 0.44 | (95.9, 98.1) |
| TRICHLOROETHYLENE | 13 | 6.81 | ( 0.0, 29.9) | 81 | 1.80 | (79.1, 82.9) | 79 | 3.19 | (71.1, 86.9) |
| BENZENE | 0 | | | 60 | 1.80 | (57.8, 62.2) | 67 | 3.19 | (63.0, 71.0) |
| ETHYL BENZENE | 33 | 6.81 | (22.2, 43.8) | 98 | 0.44 | (97.6, 98.4) | 97 | 0.44 | (95.9, 98.1) |
| TOTAL: | 46 | 6.81 | (35.2, 56.8) | 95 | 0.44 | (94.5, 95.5) | 91 | 3.19 | (83.1, 98.9) |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-10 | SPACE VELOCITY (#/HR) | 10800 | COMBUSTION AIR RATE (SCFM) | 182 |
| MIXTURE | 2 | CATALYST INLET TEMP (DEG F) | 654 | NATURAL GAS USAGE (SCFM) | 7.84 |
| DATE | 10/09/85 | CATALYST OUTLET TEMP (DEG F) | 643 | AIR TO GAS RATIO (SCF/SCF) | 23:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 74 | CATALYST PRESS DROP (INCHES H20) | 16.3 |
| | | INLET GAS FLOW RATE (SCFM) | 514 | OUTLET CARBON MONOXIDE (PPMV) | 111 |
| | | OUTLET GAS FLOW RATE (SCFM) | 696 | MOISTURE CORRECTION FACTOR | 0.954 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 12.2 | 5.14 | 0.37 | 0.46 | 96 | 0.44 | (95.4, 96.6) | 93 | 3.19 | (85.1, 100.0) |
| CYCLOHEXANE | 14.6 | 5.21 | 0.19 | 0.14 | 98 | 0.44 | (97.4, 98.6) | 96 | 0.44 | (94.9, 97.1) |
| TRICHLOROETHYLENE | 2.93 | 1.91 | 0.44 | 0.65 | 80 | 1.80 | (77.8, 82.2) | 77 | 3.19 | (69.1, 84.9) |
| BENZENE | 1.85 | 1.59 | 0.84 | 0.73 | 39 | 1.80 | (36.8, 41.2) | 47 | 3.19 | (39.1, 54.9) |
| ETHYL BENZENE | 7.52 | 3.78 | 0.09 | 0.11 | 98 | 0.44 | (97.4, 98.6) | 98 | 0.44 | (96.9, 99.1) |
| TOTAL: | 39.1 | 17.62 | 1.92 | 2.09 | 93 | 1.80 | (90.8, 95.2) | 89 | 3.19 | (81.1, 96.9) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 43 | 6.81 | (32.2, 53.8) | 95 | 0.44 | (94.4, 95.6) | 91 | 3.19 | (83.1, 98.9) |
| CYCLOHEXANE | 52 | 6.81 | (41.2, 62.8) | 99 | 0.44 | (98.4, 99.6) | 97 | 0.44 | (95.9, 98.1) |
| TRICHLOROETHYLENE | 12 | 6.81 | ( 3.5, 20.5) | 71 | 1.80 | (66.5, 75.5) | 67 | 3.19 | (59.1, 74.9) |
| BENZENE | 0 | | | 49 | 1.80 | (44.5, 53.5) | 56 | 3.19 | (48.1, 63.9) |
| ETHYL BENZENE | 32 | 6.81 | (23.5, 40.5) | 98 | 0.44 | (97.4, 98.6) | 97 | 0.44 | (95.9, 98.1) |
| TOTAL: | 39 | 6.81 | (28.2, 49.8) | 93 | 1.80 | (90.8, 95.2) | 89 | 3.19 | (81.1, 96.9) |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-11 | SPACE VELOCITY (#/HR) | 6820 | COMBUSTION AIR RATE (SCFM) | 151 |
| MIXTURE | 2 | CATALYST INLET TEMP (DEG F) | 803 | NATURAL GAS USAGE (SCFM) | 6.59 |
| DATE | 10/10/85 | CATALYST OUTLET TEMP (DEG F) | 774 | AIR TO GAS RATIO (SCF/SCF) | 23:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 88 | CATALYST PRESS DROP (INCHES H2O) | 10.4 |
|  |  | INLET GAS FLOW RATE (SCFM) | 324 | OUTLET CARBON MONOXIDE (PPMV) | 30 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 475 | MOISTURE CORRECTION FACTOR | 0.957 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 11.8 |  | 0.13 | 0.10 | 98 | 0.44 | (97.4, 98.6) |  |  |  |
| CYCLOHEXANE | 13.5 |  | 0.08 | 0.02 | 99 | 0.44 | (98.4, 99.6) |  |  |  |
| TRICHLOROETHYLENE | 2.88 |  | 0.08 | 0.05 | 96 | 0.44 | (95.4, 96.6) |  |  |  |
| BENZENE | 1.80 |  | 0.12 | 0.06 | 90 | 1.80 | (87.8, 92.2) |  |  |  |
| ETHYL BENZENE | 7.80 |  | 0.06 | 0.02 | 99 | 0.44 | (98.4, 99.6) |  |  |  |
| TOTAL: | 37.8 |  | 0.46 | 0.25 | 98 | 0.44 | (97.4, 98.6) |  |  |  |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE |  |  |  | 99 | 0.44 | (98.4, 99.6) |  |  |  |
| CYCLOHEXANE |  |  |  | 99+ | 0.44 | (99.4, 100.0) |  |  |  |
| TRICHLOROETHYLENE |  |  |  | 98 | 0.44 | (97.4, 98.6) |  |  |  |
| BENZENE |  |  |  | 96 | 0.44 | (95.4, 96.6) |  |  |  |
| ETHYL BENZENE |  |  |  | 99+ | 0.44 | (99.4, 100.0) |  |  |  |
| TOTAL: |  |  |  | 99 | 0.44 | (98.4, 99.6) |  |  |  |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-12 | SPACE VELOCITY (#/HR) | 6290 | COMBUSTION AIR RATE (SCFM) | 170 |
| MIXTURE | 2 | CATALYST INLET TEMP (DEG F) | 947 | NATURAL GAS USAGE (SCFM) | 7.81 |
| DATE | 10/11/85 | CATALYST OUTLET TEMP (DEG F) | 913 | AIR TO GAS RATIO (SCF/SCF) | 22:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 89 | CATALYST PRESS DROP (INCHES H2O) | 10.0 |
| | | INLET GAS FLOW RATE (SCFM) | 299 | OUTLET CARBON MONOXIDE (PPMV) | 6 |
| | | OUTLET GAS FLOW RATE (SCFM) | 469 | MOISTURE CORRECTION FACTOR | 0.942 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 13.4 | 2.63 | 0.04 | 0.03 | 99+ | 0.44 | (100.0, 100.0) | 98 | | ( 98.0, 98.0) |
| CYCLOHEXANE | 15.2 | 1.95 | 0.03 | 0.01 | 99+ | 0.44 | (100.0, 100.0) | 98 | | ( 98.0, 98.0) |
| TRICHLOROETHYLENE | 3.26 | 1.59 | <0.03 | 0.02 | >99 | 0.44 | (100.0, 100.0) | >99 | | (100.0, 100.0) |
| BENZENE | 2.03 | 1.74 | 0.11 | 0.03 | 92 | 1.80 | ( 92.0, 92.0) | 94 | | ( 94.0, 94.0) |
| ETHYL BENZENE | 8.22 | 2.12 | <0.03 | 0.005 | >99 | 0.44 | (100.0, 100.0) | >99 | | (100.0, 100.0) |
| TOTAL: | 42.1 | 10.02 | 0.24 | 0.09 | >99 | 0.44 | (100.0, 100.0) | >99 | | (100.0, 100.0) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 69 | 6.81 | (52.1, 85.9) | 99+ | 0.44 | (99.3, 100.0) | 99 | 0.44 | (97.9, 100.0) |
| CYCLOHEXANE | 80 | 6.81 | (63.1, 96.9) | 99+ | 0.44 | (99.3, 100.0) | 99+ | 0.44 | (98.9, 100.0) |
| TRICHLOROETHYLENE | 24 | 6.81 | ( 7.1, 40.9) | 99 | 0.44 | (98.3, 99.7) | 99 | 0.44 | (97.9, 100.0) |
| BENZENE | 0 | | | 98 | 0.44 | (97.3, 98.7) | 98 | 0.44 | (96.9, 99.1) |
| ETHYL BENZENE | 60 | 6.81 | (43.1, 76.9) | 99+ | 0.44 | (99.3, 100.0) | 99+ | 0.44 | (98.9, 100.0) |
| TOTAL: | 63 | 6.81 | (46.1, 79.9) | 99+ | 0.44 | (99.3, 100.0) | 99 | 0.44 | (97.9, 100.0) |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-13 | SPACE VELOCITY (#/HR) | 9730 | COMBUSTION AIR RATE (SCFM) | 176 |
| MIXTURE | 2 | CATALYST INLET TEMP (DEG F) | 932 | NATURAL GAS USAGE (SCFM) | 10.5 |
| DATE | 10/11/85 | CATALYST OUTLET TEMP (DEG F) | 906 | AIR TO GAS RATIO (SCF/SCF) | 17:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 87 | CATALYST PRESS DROP (INCHES H20) | 11.9 |
|  |  | INLET GAS FLOW RATE (SCFM) | 462 | OUTLET CARBON MONOXIDE (PPMV) | 33 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 638 | MOISTURE CORRECTION FACTOR | 0.942 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 13.2 | 3.65 | 0.06 | 0.04 | 99 | 0.44 | ( 98.4, 99.6) | 98 | 0.44 | ( 96.9, 99.1) |
| CYCLOHEXANE | 16.0 | 3.18 | 0.05 | <0.03 | >99 | 0.44 | ( 99.4, 100.0) | 99 | 0.44 | ( 97.9, 100.0) |
| TRICHLOROETHYLENE | 3.30 | 1.63 | <0.04 | 0.07 | 98 | 0.44 | ( 97.4, 98.6) | >99 | 0.44 | ( 98.9, 100.0) |
| BENZENE | 2.08 | 1.61 | 0.07 | 0.09 | 96 | 0.44 | ( 94.9, 97.1) | 96 | 0.44 | ( 94.9, 97.1) |
| ETHYL BENZENE | 8.34 | 2.72 | 0.06 | <0.03 | >99 | 0.44 | ( 99.4, 100.0) | 98 | 0.44 | ( 96.9, 99.1) |
| TOTAL: | 42.9 | 12.80 | 0.27 | 0.26 | 99 | 0.44 | ( 96.1, 100.0) | 98 | 0.44 | ( 96.9, 99.1) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| PENTANE | 62 | 6.81 | (51.2, 72.8) | 99+ | 0.44 | (99.4, 100.0) | 99 | 0.44 | (97.9, 100.0) |
| CYCLOHEXANE | 72 | 6.81 | (63.5, 80.5) | 99+ | 0.44 | (99.4, 100.0) | 99 | 0.44 | (97.9, 100.0) |
| TRICHLOROETHYLENE | 32 | 6.81 | (15.1, 48.9) | 97 | 0.44 | (96.4, 97.6) | 96 | 0.44 | (94.9, 97.1) |
| BENZENE | 0 |  |  | 95 | 1.80 | (92.8, 97.2) | 95 | 3.19 | (87.1, 100.0) |
| ETHYL BENZENE | 55 | 6.81 | (46.5, 63.5) | 99+ | 0.44 | (99.4, 100.0) | 99 | 0.44 | (97.9, 100.0) |
| TOTAL: | 59 | 6.81 | (48.2, 69.8) | 99 | 0.44 | (98.4, 99.6) | 98 | 0.44 | (96.9, 99.1) |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-14 | SPACE VELOCITY (#/HR) | 10400 | COMBUSTION AIR RATE (SCFM) | 141 |
| MIXTURE | 2 | CATALYST INLET TEMP (DEG F) | 801 | NATURAL GAS USAGE (SCFM) | 8.85 |
| DATE | 10/13/85 | CATALYST OUTLET TEMP (DEG F) | 784 | AIR TO GAS RATIO (SCF/SCF) | 16:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 84 | CATALYST PRESS DROP (INCHES H20) | 11.4 |
|  |  | INLET GAS FLOW RATE (SCFM) | 495 | OUTLET CARBON MONOXIDE (PPMV) | 77 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 636 | MOISTURE CORRECTION FACTOR | 0.952 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | STD. | 95% C.I. |  | STD. | 95% C.I. |
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| PENTANE | 12.8 | 4.71 | 0.13 | 0.14 | 99 | 0.44 | (98.4, 99.6) | 97 | 0.44 | (95.9, 98.1) |
| CYCLOHEXANE | 15.4 | 4.84 | 0.09 | 0.03 | 99 | 0.44 | (98.4, 99.6) | 98 | 0.44 | (96.9, 99.1) |
| TRICHLOROETHYLENE | 3.42 | 2.36 | 0.14 | 0.10 | 95 | 1.80 | (90.5, 99.5) | 94 | 3.19 | (86.1, 100.0) |
| BENZENE | 2.17 | 1.97 | 0.19 | 0.12 | 89 | 1.80 | (86.8, 91.2) | 91 | 3.19 | (83.1, 98.9) |
| ETHYL BENZENE | 9.05 | 4.58 | 0.06 | 0.02 | 99 | 0.44 | (98.4, 99.6) | 99 | 0.44 | (97.9, 100.0) |
| TOTAL: | 42.8 | 18.46 | 0.59 | 0.41 | 98 | 0.44 | (95.8, 100.0) | 97 | 0.44 | (95.9, 98.1) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | STD. | 95% C.I. |  | STD. | 95% C.I. |  | STD. | 95% C.I. |
| SPECIES | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| PENTANE | 53 | 6.81 | (44.5. 61.5) | 99 | 0.44 | (98.4, 99.6) | 97 | 0.44 | (95.9, 98.1) |
| CYCLOHEXANE | 59 | 6.81 | (48.2, 69.8) | 99+ | 0.44 | (99.4, 100.0) | 99 | 0.44 | (97.9, 100.0) |
| TRICHLOROETHYLENE | 11 | 6.81 | ( 0.0, 27.9) | 96 | 0.44 | (95.4, 96.6) | 96 | 0.44 | (94.9, 97.1) |
| BENZENE | 0 |  |  | 93 | 1.80 | (90.8. 95.2) | 94 | 3.19 | (86.1, 100.0) |
| ETHYL BENZENE | 35 | 6.81 | (24.2, 45.8) | 99+ | 0.44 | (99.4, 100.0) | 99+ | 0.44 | (98.9, 100.0) |
| TOTAL: | 45 | 6.81 | (34.2, 55.8) | 99 | 0.44 | (98.4, 99.6) | 98 | 0.44 | (96.9, 99.1) |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-15 | SPACE VELOCITY (#/HR) | 9960 | COMBUSTION AIR RATE (SCFM) | 153 |
| MIXTURE | 1 | CATALYST INLET TEMP (DEG F) | 801 | NATURAL GAS USAGE (SCFM) | 8.62 |
| DATE | 10/14/85 | CATALYST OUTLET TEMP (DEG F) | 778 | AIR TO GAS RATIO (SCF/SCF) | 18:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 92 | CATALYST PRESS DROP (INCHES H20) | 10.7 |
|  |  | INLET GAS FLOW RATE (SCFM) | 473 | OUTLET CARBON MONOXIDE (PPMV) | 53 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 626 | MOISTURE CORRECTION FACTOR | 0.949 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHYLENE | 10.5 | 4.86 | 0.82 |  | 90 | 1.80 | (88.3, 91.7) | 83 | 3.19 | (75.1, 90.9) |
| TRICHLOROETHYLENE | 7.35 | 3.11 | 0.27 |  | 95 | 0.44 | (94.6, 95.4) | 91 | 3.19 | (83.1, 98.9) |
| TOTAL: | 17.8 | 7.97 | 1.09 |  | 92 | 1.80 | (90.3, 93.7) | 86 | 3.19 | (78.1, 93.9) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHYLENE | 39 | 6.81 | (32.7, 45.3) |  |  |  |  |  |  |
| TRICHLOROETHYLENE | 44 | 6.81 | (36.8, 51.2) |  |  |  |  |  |  |
| TOTAL: | 41 | 6.81 | (34.7, 47.3) |  |  |  |  |  |  |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-16 | SPACE VELOCITY (#/HR) | 7430 | COMBUSTION AIR RATE (SCFM) | 130 |
| MIXTURE | 4 | CATALYST INLET TEMP (DEG F) | 649 | NATURAL GAS USAGE (SCFM) | 5.21 |
| DATE | 10/15/85 | CATALYST OUTLET TEMP (DEG F) | 632 | AIR TO GAS RATIO (SCF/SCF) | 25:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 93 | CATALYST PRESS DROP (INCHES H2O) | 9.2 |
| | | INLET GAS FLOW RATE (SCFM) | 353 | OUTLET CARBON MONOXIDE (PPMV) | 57 |
| | | OUTLET GAS FLOW RATE (SCFM) | 483 | MOISTURE CORRECTION FACTOR | 0.000 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHANE | 11.1 | 5.05 | 1.41 | | 83 | 1.80 | (78.5, 87.5) | 72 | 3.19 | (64.1, 79.9) |
| TRICHLOROETHYLENE | 10.9 | 6.59 | 1.14 | | 86 | 1.80 | (83.1, 88.9) | 83 | 3.19 | (75.1, 90.9) |
| 1,1,2 - TRICHLOROETHANE | 10.2 | 5.86 | 1.53 | | 80 | 1.80 | (77.1, 82.9) | 74 | 3.19 | (66.1, 81.9) |
| TETRACHLOROETHANE | 9.97 | 6.48 | 3.62 | | 50 | 1.80 | (47.1, 52.9) | 44 | 3.19 | (36.1, 51.9) |
| TOTAL: | 42.2 | 23.99 | 7.70 | | 75 | 1.80 | (72.1, 77.9) | 68 | 3.19 | (60.1, 75.9) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHANE | 38 | 6.81 | (21.1, 54.9) | | | | | | |
| TRICHLOROETHYLENE | 17 | 6.81 | ( 0.1, 33.9) | | | | | | |
| 1,1,2 - TRICHLOROETHANE | 21 | 6.81 | ( 4.1, 37.9) | | | | | | |
| TETRACHLOROETHANE | 11 | 6.81 | ( 0.2, 21.8) | | | | | | |
| TOTAL: | 22 | 6.81 | ( 5.1, 38.9) | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RUN # | B-17 | SPACE VELOCITY (#/HR) | 10600 | COMBUSTION AIR RATE (SCFM) | 176 |
| MIXTURE | 4 | CATALYST INLET TEMP (DEG F) | 653 | NATURAL GAS USAGE (SCFM) | 7.61 |
| DATE | 10/15/85 | CATALYST OUTLET TEMP (DEG F) | 635 | AIR TO GAS RATIO (SCF/SCF) | 23:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 71 | CATALYST PRESS DROP (INCHES H2O) | 11.3 |
| | | INLET GAS FLOW RATE (SCFM) | 503 | OUTLET CARBON MONOXIDE (PPMV) | 90 |
| | | OUTLET GAS FLOW RATE (SCFM) | 673 | MOISTURE CORRECTION FACTOR | 0.000 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHANE | 12.4 | 6.34 | 2.10 | | 77 | 1.80 | (74.1, 79.9) | 67 | 3.19 | (59.1, 74.9) |
| TRICHLOROETHYLENE | 12.9 | 7.60 | 1.77 | | 82 | 1.80 | (79.1, 84.9) | 77 | 3.19 | (69.1, 84.9) |
| 1,1,2 - TRICHLOROETHANE | 12.7 | 7.25 | 2.26 | | 76 | 1.80 | (73.1, 78.9) | 69 | 3.19 | (61.1, 76.9) |
| TETRACHLOROETHANE | 12.3 | 8.70 | 4.49 | | 51 | 1.80 | (48.1, 53.9) | 48 | 3.19 | (40.1, 55.9) |
| TOTAL: | 50.2 | 29.89 | 10.61 | | 72 | 1.80 | (69.1, 74.9) | 64 | 3.19 | (56.1, 71.9) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1.2 - DICHLOROETHANE | 31 | 6.81 | (20.2, 41.8) | | | | | | |
| TRICHLOROETHYLENE | 21 | 6.81 | (10.2, 31.8) | | | | | | |
| 1,1.2 - TRICHLOROETHANE | 23 | 6.81 | (12.2, 33.8) | | | | | | |
| TETRACHLOROETHANE | 5 | 6.81 | ( 0.0, 21.9) | | | | | | |
| TOTAL: | 20 | 6.81 | ( 9.2, 30.8) | | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-18 | SPACE VELOCITY (#/HR) | 6530 | COMBUSTION AIR RATE (SCFM) | 147 |
| MIXTURE | 4 | CATALYST INLET TEMP (DEG F) | 952 | NATURAL GAS USAGE (SCFM) | 7.37 |
| DATE | 10/16/85 | CATALYST OUTLET TEMP (DEG F) | 917 | AIR TO GAS RATIO (SCF/SCF) | 20:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 84 | CATALYST PRESS DROP (INCHES H20) | 10.2 |
| | | INLET GAS FLOW RATE (SCFM) | 310 | OUTLET CARBON MONOXIDE (PPMV) | 32 |
| | | OUTLET GAS FLOW RATE (SCFM) | 437 | MOISTURE CORRECTION FACTOR | 0.950 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | STD. | 95% C.I. | | STD. | 95% C.I. |
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1,2 - DICHLOROETHANE | 11.2 | 2.07 | 0.07 | 0.04 | 99 | 0.44 | (98.3, 99.7) | 96 | 0.44 | (94.9, 97.1) |
| TRICHLOROETHYLENE | 11.9 | 4.10 | 0.17 | 0.12 | 98 | 0.44 | (97.3, 98.7) | 96 | 0.44 | (94.9, 97.1) |
| 1,1,2 - TRICHLOROETHANE | 11.7 | 3.23 | 0.13 | 0.05 | 98 | 0.44 | (97.3, 98.7) | 96 | 0.44 | (94.9, 97.1) |
| TETRACHLOROETHANE | 11.7 | 5.68 | 0.76 | 0.35 | 91 | 1.80 | (88.8, 93.2) | 87 | 3.19 | (79.1, 94.9) |
| TOTAL: | 46.5 | 15.08 | 1.13 | 0.55 | 97 | 0.44 | (96.3, 97.7) | 93 | 3.19 | (85.1, 100.0) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | STD. | 95% C.I. | | STD. | 95% C.I. | | STD. | 95% C.I. |
| SPECIES | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1.2 - DICHLOROETHANE | 74 | 6.81 | (57.1, 90.9) | 99+ | 0.44 | (99.3, 100.0) | 98 | 0.44 | (96.9, 99.1) |
| TRICHLOROETHYLENE | 51 | 6.81 | (34.1, 67.9) | 99 | 0.44 | (98.3, 99.7) | 97 | 0.44 | (95.9, 98.1) |
| 1.1.2 - TRICHLOROETHANE | 61 | 6.81 | (44.1, 77.9) | 99 | 0.44 | (98.3, 99.7) | 99 | 0.44 | (97.9, 100.0) |
| TETRACHLOROETHANE | 31 | 6.81 | (14.1, 47.9) | 96 | 0.44 | (95.3, 96.7) | 94 | 3.19 | (86.1, 100.0) |
| TOTAL: | 54 | 6.81 | (37.1, 70.9) | 98 | 0.44 | (97.3, 98.7) | 97 | 0.44 | (95.9, 98.1) |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-19 | SPACE VELOCITY (#/HR) | 10000 | COMBUSTION AIR RATE (SCFM) | 182 |
| MIXTURE | 4 | CATALYST INLET TEMP (DEG F) | 953 | NATURAL GAS USAGE (SCFM) | 11.4 |
| DATE | 10/16/85 | CATALYST OUTLET TEMP (DEG F) | 926 | AIR TO GAS RATIO (SCF/SCF) | 16:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 62 | CATALYST PRESS DROP (INCHES H20) | 12.0 |
|  |  | INLET GAS FLOW RATE (SCFM) | 476 | OUTLET CARBON MONOXIDE (PPMV) | 40 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 658 | MOISTURE CORRECTION FACTOR | 0.949 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHANE | 13.2 | 4.63 | 0.16 | 0.12 | 98 | 0.44 | (97.4, 98.6) | 97 | 0.44 | (95.9, 98.1) |
| TRICHLOROETHYLENE | 13.9 | 5.75 | 0.22 | 0.23 | 98 | 0.44 | (97.4, 98.6) | 96 | 0.44 | (94.9, 97.1) |
| 1,1,2 - TRICHLOROETHANE | 14.4 | 5.44 | 0.13 | 0.10 | 99 | 0.44 | (98.4, 99.6) | 98 | 0.44 | (96.9, 99.1) |
| TETRACHLOROETHANE | 15.6 | 6.84 | 1.06 | 0.90 | 91 | 1.80 | (88.8, 93.2) | 85 | 3.19 | (77.1, 92.9) |
| TOTAL: | 57.1 | 22.66 | 1.57 | 1.34 | 96 | 0.44 | (95.4, 96.6) | 93 | 3.19 | (85.1, 100.0) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHANE | 52 | 6.81 | (41.2, 62.8) | 99 | 0.44 | (98.4, 99.6) | 98 | 0.44 | (96.9, 99.1) |
| TRICHLOROETHYLENE | 43 | 6.81 | (26.1, 59.9) | 98 | 0.44 | (97.4, 98.6) | 96 | 0.44 | (94.9, 97.1) |
| 1,1,2 - TRICHLOROETHANE | 48 | 6.81 | (31.1, 64.9) | 99 | 0.44 | (98.4, 99.6) | 98 | 0.44 | (96.9, 99.1) |
| TETRACHLOROETHANE | 39 | 6.81 | (22.1, 55.9) | 92 | 1.80 | (89.8, 94.2) | 88 | 3.19 | (80.1, 95.9) |
| TOTAL: | 45 | 6.81 | (28.1, 61.9) | 97 | 0.44 | (96.4, 97.6) | 94 | 3.19 | (92.9, 95.1) |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-20 | SPACE VELOCITY (#/HR) | 7770 | COMBUSTION AIR RATE (SCFM) | 159 |
| MIXTURE | 4 | CATALYST INLET TEMP (DEG F) | 654 | NATURAL GAS USAGE (SCFM) | 5.85 |
| DATE | 10/18/83 | CATALYST OUTLET TEMP (DEG F) | 636 | AIR TO GAS RATIO (SCF/SCF) | 27:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 83 | CATALYST PRESS DROP (INCHES H2O) | 9.4 |
| | | INLET GAS FLOW RATE (SCFM) | 369 | OUTLET CARBON MONOXIDE (PPMV) | 66 |
| | | OUTLET GAS FLOW RATE (SCFM) | 528 | MOISTURE CORRECTION FACTOR | 0.958 |

| | | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | AVERAGE CONCENTRATION (PPMV) | | | | | STD. | 95% C.I. | | STD. | 95% C.I. |
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1,2 - DICHLOROETHANE | 10.8 | 5.06 | 1.35 | | 82 | 1.80 | (79.8, 84.2) | 76 | 3.19 | (68.1, 83.9) |
| TRICHLOROETHYLENE | 10.9 | 6.38 | 1.04 | | 86 | 1.80 | (83.8, 88.2) | 84 | 3.19 | (78.9, 89.1) |
| 1,1,2 - TRICHLOROETHANE | 10.7 | 6.26 | 1.43 | | 81 | 1.80 | (78.8, 83.2) | 77 | 3.19 | (69.1, 84.9) |
| TETRACHLOROETHANE | 11.1 | 7.33 | 3.51 | | 55 | 1.80 | (52.8, 57.2) | 52 | 3.19 | (44.1, 59.9) |
| TOTAL: | 43.6 | 25.63 | 7.33 | | 76 | 1.80 | (73.8, 78.2) | 71 | 3.19 | (63.1, 78.9) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | STD. | 95% C.I. | | STD. | 95% C.I. | | STD. | 95% C.I. |
| SPECIES | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1,2 - DICHLOROETHANE | 25 | 6.81 | (14.2, 35.8) | | | | | | |
| TRICHLOROETHYLENE | 16 | 6.81 | ( 7.5, 24.5) | | | | | | |
| 1,1,2 - TRICHLOROETHANE | 17 | 6.81 | ( 6.2, 27.8) | | | | | | |
| TETRACHLOROETHANE | 5 | 6.81 | ( 0.0, 15.8) | | | | | | |
| TOTAL: | 16 | 6.81 | ( 5.2, 26.8) | | | | | | |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-22 | SPACE VELOCITY (#/HR) | 11200 | COMBUSTION AIR RATE (SCFM) | 144 |
| MIXTURE | 4 | CATALYST INLET TEMP (DEG F) | 660 | NATURAL GAS USAGE (SCFM) | 7.77 |
| DATE | 10/22/85 | CATALYST OUTLET TEMP (DEG F) | 645 | AIR TO GAS RATIO (SCF/SCF) | 19:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 66 | CATALYST PRESS DROP (INCHES H2O) | 11.5 |
|  |  | INLET GAS FLOW RATE (SCFM) | 530 | OUTLET CARBON MONOXIDE (PPMV) | 169 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 674 | MOISTURE CORRECTION FACTOR | 0.000 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | STD. | 95% C.I. |  | STD. | 95% C.I. |
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1,2 - DICHLOROETHANE | 45.9 | 25.6 | 7.03 |  | 81 | 1.80 | (78.8, 83.2) | 72 | 3.19 | (66.9, 77.1) |
| TRICHLOROETHYLENE | 48.3 | 31.7 | 7.97 |  | 79 | 1.80 | (76.8, 81.2) | 75 | 3.19 | (69.9, 80.1) |
| 1,1,2 - TRICHLOROETHANE | 47.5 | 28.9 | 8.29 |  | 78 | 1.80 | (75.8, 80.2) | 71 | 3.19 | (65.9, 76.1) |
| TETRACHLOROETHANE | 50.3 | 35.1 | 18.8 |  | 52 | 1.80 | (49.1, 54.9) | 46 | 3.19 | (40.9, 51.1) |
| TOTAL: | 192.0 | 121.2 | 42.1 |  | 72 | 1.80 | (69.8, 74.2) | 65 | 3.19 | (59.9, 70.1) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | STD. | 95% C.I. |  | STD. | 95% C.I. |  | STD. | 95% C.I. |
| SPECIES | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN | MEAN | DEV. | ON THE MEAN |
| 1.2 - DICHLOROETHANE | 28 | 6.81 | (18.2, 39.8) |  |  |  |  |  |  |
| TRICHLOROETHYLENE | 17 | 6.81 | ( 6.2, 27.8) |  |  |  |  |  |  |
| 1.1.2 - TRICHLOROETHANE | 23 | 6.81 | (12.2, 33.8) |  |  |  |  |  |  |
| TETRACHLOROETHANE | 11 | 6.81 | ( 2.5, 19.5) |  |  |  |  |  |  |
| TOTAL: | 20 | 6.81 | ( 9.2, 30.8) |  |  |  |  |  |  |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-23 | SPACE VELOCITY (#/HR) | 10200 | COMBUSTION AIR RATE (SCFM) | 231 |
| MIXTURE | 4 | CATALYST INLET TEMP (DEG F) | 953 | NATURAL GAS USAGE (SCFM) | 12.1 |
| DATE | 10/23/85 | CATALYST OUTLET TEMP (DEG F) | 931 | AIR TO GAS RATIO (SCF/SCF) | 19:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 76 | CATALYST PRESS DROP (INCHES H2O) | 11.6 |
|  |  | INLET GAS FLOW RATE (SCFM) | 482 | OUTLET CARBON MONOXIDE (PPMV) | 56 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 713 | MOISTURE CORRECTION FACTOR | 0.000 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
|  |  | • |  |  |  |  |  |  |  |  |
| 1,2 - DICHLOROETHANE | 51.6 | 17.0 | 0.86 |  | 98 | 0.44 | (97.5, 98.5) | 95 | 3.19 | (89.9, 100.0) |
| TRICHLOROETHYLENE | 53.4 | 24.2 | 1.15 |  | 97 | 0.44 | (96.5, 97.5) | 95 | 0.44 | (94.3, 95.7) |
| 1,1,2 - TRICHLOROETHANE | 55.1 | 20.5 | 0.66 |  | 98 | 0.44 | (97.5, 98.5) | 97 | 0.44 | (96.3, 97.7) |
| TETRACHLOROETHANE | 55.5 | 31.5 | 4.13 |  | 89 | 1.80 | (87.1, 90.9) | 87 | 3.19 | (81.9, 92.1) |
| TOTAL: | 215.6 | 93.2 | 6.80 |  | 95 | 0.44 | (94.5, 95.5) | 93 | 3.19 | (87.9, 98.1) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| 1,2 - DICHLOROETHANE | 51 | 6.81 | (43.8, 58.2) |  |  |  |  |  |  |
| TRICHLOROETHYLENE | 33 | 6.81 | (25.8, 40.2) |  |  |  |  |  |  |
| 1,1,2 - TRICHLOROETHANE | 45 | 6.81 | (37.8, 52.2) |  |  |  |  |  |  |
| TETRACHLOROETHANE | 16 | 6.81 | ( 5.2, 26.8) |  |  |  |  |  |  |
| TOTAL: | 36 | 6.81 | (28.8, 43.2) |  |  |  |  |  |  |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-24 | SPACE VELOCITY (#/HR) | 6530 | COMBUSTION AIR RATE (SCFM) | 159 |
| MIXTURE | 4 | CATALYST INLET TEMP (DEG F) | 952 | NATURAL GAS USAGE (SCFM) | 7.99 |
| DATE | 10/24/85 | CATALYST OUTLET TEMP (DEG F) | 911 | AIR TO GAS RATIO (SCF/SCF) | 20:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | •75 | CATALYST PRESS DROP (INCHES H2O) | 9.9 |
|  |  | INLET GAS FLOW RATE (SCFM) | 310 | OUTLET CARBON MONOXIDE (PPMV) | 6 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 469 | MOISTURE CORRECTION FACTOR | 0.000 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | 7.01 | 2.09 | 0.07 |  | 99 | 0.44 | ( 98.4, 99.6) | 97 | 0.44 | ( 95.9, 98.1) |
| TRICHLOROETHYLENE | 1.70 | 0.47 | <0.08 |  | >99 | 1.80 | ( 97.8, 100.0) | >99 | 3.19 | ( 92.1, 100.0) |
| TOTAL: | 8.71 | 2.56 | 0.15 |  | >99 |  | ( 99.4, 100.0) | >99 |  | ( 92.1, 100.0) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | 55 | 6.81 | (44.2, 65.8) |  |  |  |  |  |  |
| TRICHLOROETHYLENE | 57 | 6.81 | (49.5, 66.5) |  |  |  |  |  |  |
| TOTAL: | 56 | 6.81 | (47.5, 64.5) |  |  |  |  |  |  |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-25 | SPACE VELOCITY (#/HR) | 7350 | COMBUSTION AIR RATE (SCFM) | 163 |
| MIXTURE | 3 | CATALYST INLET TEMP (DEG F) | 656 | NATURAL GAS USAGE (SCFM) | 5.73 |
| DATE | 10/25/85 | CATALYST OUTLET TEMP (DEG F) | 637 | AIR TO GAS RATIO (SCF/SCF) | 29:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 82 | CATALYST PRESS DROP (INCHES H2O) | 9.6 |
| | | INLET GAS FLOW RATE (SCFM) | 349 | OUTLET CARBON MONOXIDE (PPMV) | 50 |
| | | OUTLET GAS FLOW RATE (SCFM) | 514 | MOISTURE CORRECTION FACTOR | 0.000 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | 8.53 | 4.62 | 0.35 | | 94 | 1.80 | (91.1, 96.9) | 92 | 3.19 | (84.1, 99.9) |
| TRICHLOROETHYLENE | 2.36 | 1.65 | 0.24 | | 85 | 1.80 | (82.1, 87.9) | 86 | 3.19 | (78.1, 93.9) |
| TOTAL: | 10.88 | 6.26 | 0.58 | | 92 | 1.80 | (89.1, 94.9) | 91 | 3.19 | (83.1, 98.9) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | 20 | 6.81 | ( 3.1, 36.9) | | | | | | |
| TRICHLOROETHYLENE | 0 | | | | | | | | |
| TOTAL: | 15 | 6.81 | ( 4.2, 25.8) | | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-26 | SPACE VELOCITY (#/HR) | 11300 | COMBUSTION AIR RATE (SCFM) | 147 |
| MIXTURE | 3 | CATALYST INLET TEMP (DEG F) | 648 | NATURAL GAS USAGE (SCFM) | 7.64 |
| DATE | 10/25/85 | CATALYST OUTLET TEMP (DEG F) | 629 | AIR TO GAS RATIO (SCF/SCF) | 19:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 73 | CATALYST PRESS DROP (INCHES H2O) | 10.6 |
| | | INLET GAS FLOW RATE (SCFM) | 537 | OUTLET CARBON MONOXIDE (PPMV) | 96 |
| | | OUTLET GAS FLOW RATE (SCFM) | 684 | MOISTURE CORRECTION FACTOR | 0.000 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | 10.1 | 5.59 | 0.69 | | 91 | 1.80 | (88.1, 93.9) | 88 | 3.19 | (82.9, 93.1) |
| TRICHLOROETHYLENE | 2.27 | 1.46 | 0.34 | | 81 | 1.80 | (78.1, 83.9) | 77 | 3.19 | (71.9, 82.1) |
| TOTAL: | 12.4 | 7.05 | 1.03 | | 89 | 1.80 | (86.1, 91.9) | 85 | 3.19 | (79.9, 90.1) |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | 28 | 6.81 | (18.2, 39.8) | | | | | | |
| TRICHLOROETHYLENE | 18 | 6.81 | ( 7.2, 28.8) | | | | | | |
| TOTAL: | 27 | 6.81 | (16.2, 37.8) | | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| RUN # | B-27 | SPACE VELOCITY (#/HR) | 6970 | COMBUSTION AIR RATE (SCFM) | 171 |
| MIXTURE | 3 | CATALYST INLET TEMP (DEG F) | 798 | NATURAL GAS USAGE (SCFM) | 7.07 |
| DATE | 10/28/85 | CATALYST OUTLET TEMP (DEG F) | 765 | AIR TO GAS RATIO (SCF/SCF) | 24:1 |
| | | INCINERATOR INLET TEMP (DEG F) | 73 | CATALYST PRESS DROP (INCHES H20) | 10.0 |
| | | INLET GAS FLOW RATE (SCFM) | 331 | OUTLET CARBON MONOXIDE (PPMV) | 21 |
| | | OUTLET GAS FLOW RATE (SCFM) | 502 | MOISTURE CORRECTION FACTOR | 0.000 |

| | AVERAGE CONCENTRATION (PPMV) | | | | SYSTEM DESTRUCTION GC/FID (%) | | | CATALYST DESTRUCTION GC/FID (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | 8.63 | | 0.19 | | 97 | 0.44 | (96.3, 97.7) | | | |
| TRICHLOROETHYLENE | 1.83 | | 0.05 | | 96 | 0.44 | (95.3, 96.7) | | | |
| TOTAL: | 10.46 | | 0.24 | | 97 | 0.44 | (96.3, 97.7) | | | |

| | HEATER DESTRUCTION GC/FID (%) | | | SYSTEM DESTRUCTION TENAX (%) | | | CATALYST DESTRUCTION TENAX (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | | | | | | | | | |
| TRICHLOROETHYLENE | | | | | | | | | |
| TOTAL: | | | | | | | | | |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| RUN # | B-28 | SPACE VELOCITY (#/HR) | 10500 | COMBUSTION AIR RATE (SCFM) | 119 |
| MIXTURE | 3 | CATALYST INLET TEMP (DEG F) | 947 | NATURAL GAS USAGE (SCFM) | 10.6 |
| DATE | 10/28/85 | CATALYST OUTLET TEMP (DEG F) | 919 | AIR TO GAS RATIO (SCF/SCF) | 11:1 |
|  |  | INCINERATOR INLET TEMP (DEG F) | 61 | CATALYST PRESS DROP (INCHES H2O) | 11.9 |
|  |  | INLET GAS FLOW RATE (SCFM) | 500 | OUTLET CARBON MONOXIDE (PPMV) | 33 |
|  |  | OUTLET GAS FLOW RATE (SCFM) | 619 | MOISTURE CORRECTION FACTOR | 0.000 |

|  | AVERAGE CONCENTRATION (PPMV) |  |  |  | SYSTEM DESTRUCTION GC/FID (%) |  |  | CATALYST DESTRUCTION GC/FID (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| SPECIES | INLET | PREHEATER | GC OUTLET | TENAX OUTLET | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | 8.20 | 3.06 | 0.10 |  | 98 | 0.44 | (97.3, 98.7) | 97 | 0.44 | (95.9, 98.1) |
| TRICHLOROETHYLENE | 1.72 | 0.70 | 0.03 |  | 98 | 0.44 | (97.3, 98.7) | 95 | 0.44 | (93.9, 96.1) |
| TOTAL: | 9.92 | 3.76 | 0.13 |  | 98 | 0.44 | (97.3, 98.7) | 97 | 0.44 | (95.9, 98.1) |

|  | HEATER DESTRUCTION GC/FID (%) |  |  | SYSTEM DESTRUCTION TENAX (%) |  |  | CATALYST DESTRUCTION TENAX (%) |  |  |
|---|---|---|---|---|---|---|---|---|---|
| SPECIES | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN | MEAN | STD. DEV. | 95% C.I. ON THE MEAN |
| VINYL CHLORIDE | 54 | 6.81 | (37.1, 70.9) |  |  |  |  |  |  |
| TRICHLOROETHYLENE | 49 | 6.81 | (38.2, 59.8) |  |  |  |  |  |  |
| TOTAL: | 53 | 6.81 | (42.2, 63.8) |  |  |  |  |  |  |

```
RUN #        B-29  SPACE VELOCITY (#/HR)            10700      COMBUSTION AIR RATE (SCFM)             161
MIXTURE         1  CATALYST INLET TEMP (DEG F)        801      NATURAL GAS USAGE (SCFM)              9.59
DATE     10/29/85  CATALYST OUTLET TEMP (DEG F)       780      AIR TO GAS RATIO (SCF/SCF)            17:1
                   INCINERATOR INLET TEMP (DEG F)      62      CATALYST PRESS DROP (INCHES H2O)      11.8
                   INLET GAS FLOW RATE (SCFM)         507      OUTLET CARBON MONOXIDE (PPMV)           74
                   OUTLET GAS FLOW RATE (SCFM)        668      MOISTURE CORRECTION FACTOR           0.000


                                                               :SYSTEM DESTRUCTION GC/FID (%):CATALYST DESTRUCTION GC/FID (%)
                               AVERAGE CONCENTRATION (PPMV)    :         STD.    95% C.I.    :        STD.      95% C.I.     :
 SPECIES                   INLET  PREHEATER  GC OUTLET TENAX OUTLET: MEAN  DEV.  ON THE MEAN  :  MEAN  DEV.    ON THE MEAN    :
---------------------------------------------------------------------------------------------------------------------------------
                                                               :                              :
1,2 - DICHLOROETHYLENE     10.2     4.66       0.37            :  95    0.44  (94.3,  95.7)  :  92   3.19   (88.0,  96.0)  :
TRICHLOROETHYLENE          7.51     3.55       0.32            :  94    1.80  (91.1,  96.9)  :  91   3.19   (87.0,  95.0)  :
                                                               :                              :
TOTAL:                     17.7     8.22       0.68            :  95    0.44  (92.1,  97.9)  :  92   3.19   (88.0,  96.0)  :


                           HEATER DESTRUCTION GC/FID (%) :    SYSTEM DESTRUCTION TENAX (%)     :  CATALYST DESTRUCTION TENAX (%)  :
                                 STD.      95% C.I.      :            STD.      95% C.I.       :          STD.     95% C.I.       :
 SPECIES                   MEAN  DEV.     ON THE MEAN    :   MEAN    DEV.     ON THE MEAN      :  MEAN    DEV.   ON THE MEAN      :
----------------------------------------------------------------------------------------------------------------------------------
                                                         :                                     :                                  :
1,2 - DICHLOROETHYLENE      40   6.81    (31.5,  48.5)   :                                     :                                  :
TRICHLOROETHYLENE           38   6.81    (27.2,  48.8)   :                                     :                                  :
                                                         :                                     :                                  :
TOTAL:                      39   6.81    (30.5,  47.5)   :                                     :                                  :
. EJECYCT
```

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

|  |  |  |
|---|---|---|
| 1. REPORT NO.<br>EPA-600/2-86-079 | 2. | 3. RECIPIENT'S ACCESSION NO. |
| 4. TITLE AND SUBTITLE<br>Destruction of Chlorinated Hydrocarbons by Catalytic Oxidation | | 5. REPORT DATE<br>September 1986<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) M. A. Palazzolo, C. L. Jamgochian, J. I. Steinmetz, and D. L. Lewis | | 8. PERFORMING ORGANIZATION REPORT NO.<br>DCN 86-203-023-34-11 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Radian Corporation<br>Progress Center<br>3200 E. Chapel Hill Road/Nelson Highway<br>Research Triangle Park, North Carolina 27709 | | 10. PROGRAM ELEMENT NO.<br>11. CONTRACT/GRANT NO.<br>68-02-3994, Tasks 20/34 |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>**EPA, Office of Research and Development***<br>**Air and Energy Engineering Research Laboratory**<br>**Research Triangle Park, NC 27711** | | 13. TYPE OF REPORT AND PERIOD COVERED<br>Task Final; 8/85 - 7/86<br>14. SPONSORING AGENCY CODE<br>**EPA/600/13** |

15. SUPPLEMENTARY NOTES AEERL project officer is Bruce A. Tichenor, Mail Drop 54, 919/2991. (*)Cosponsored by U.S. Air Force, Tyndall Air Force Base, FL 32403 (USAF project officer, CAPT Richard A. Ashworth), USAF IAG RW57931254.

16. ABSTRACT The report gives results of a determination of the effectiveness of catalytic oxidation for destroying vapor-phase chlorinated hydrocarbons. The study was conducted on two pilot-scale catalytic incinerators: one employed a metal oxide catalyst in a fluidized-bed configuration; and the other, a fixed-bed proprietary catalyst, supplemented with ultraviolet (UV) light and ozone injection. Both systems were tested under a variety of temperature and space velocities. The test vapor streams consisted of low concentrations (3-200 ppmv) of mixtures of organic compounds, and included three streams that represented emissions from air strippers used to treat contaminated groundwater at U.S. Air Force bases. Study results showed that the fluidized-bed catalytic incinerator was capable of achieving total organic destruction efficiencies of greater than 98%. The UV/ozone catalytic incinerator failed to achieve high destruction efficiencies: with ozone injection, total destruction was 75%; and without ozone, the maximum destruction efficiency was 64%.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group | |
|---|---|---|---|---|
| Pollution | Fluidizing | Pollution Control | 13B | 07A, 13H |
| Chlorohydrocarbons | Ultraviolet Sources | Stationary Sources | 07C | 14B |
| Organic Compounds | Ozone | Catalytic Oxidation | | |
| Incinerators | | Air Strippers | | |
| Catalysis | | | 07D | |
| Oxidation | | | 07B | |

|  |  |  |
|---|---|---|
| 18. DISTRIBUTION STATEMENT<br>**Release to Public** | 19. SECURITY CLASS *(This Report)*<br>Unclassified | 21. NO. OF PAGES<br>149 |
| | 20. SECURITY CLASS *(This page)*<br>Unclassified | 22. PRICE |

EPA Form 2220-1 (9-73)